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THE MEASUREMENT OF SUB-MARINE LIGHT AND ITS RELATIONSHIP TO BIOLOGICAL PHENOMENA

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1.

SUBMARINE ILLUMINATION IN RELATION TO ANIMAL LIFE.

BY

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SUBMARINE illumination is one of the conditions of the environment which shows the greatest fluctuations. While such conditions salinity and temperature may remain relatively nstant for long periods of time, the illumination the upper layers and shallow waters may vary •m that of full sunlight to complete darkness ring 24 hours. Under such widely varying illunation it is natural to find that many species of imals are able to withstand a considerable range intensities of light. Nevertheless, probably all imals react in some way towards changes in light nditions and each species tends to seek an timum of intensity and composition, having an per maximum condition which it avoids and a ver threshold of illumination below which it ases to react. The values of these points on the ht scale of an animal's requirements vary for :h species, and within any one species during its e history and at different seasons of the year. Now that accurate methods for the measurement the strength and composition of light beneath the surface have been evolved, it is necessary that ecological observations should include the study light as one of the factors of the environment. I propose to summarize briefly such obser-ions as have already been made and draw ention to certain aspects in the study of animal e in the sea in which light conditions play an portant controlling influence. In doing this I ll lay most stress on the work on plankton mals; but I shall also consider the relation of umination with other marine animal communities this will assist in emphasizing, if that be neces-y, the need for a more complete knowledge of variations in submarine illumination from ce to place and time to time.

Our present knowledge of the relations of sub-rine illumination with animal life may be sum-rized under the following headings.

1. Zooplankton.
   a. Light and vertical distribution.
   b. Physiological effects of light on plankton animals.
   c. Light in relation to zooplankton production and distribution.
2. Bottom Fauna.
   a. Light and the zonation of sedentary and bottom animals.
   b. Physiological effects of light on bottom animals.
3. Fishes.
   a. Light discrimination.
   b. Physiological effects of light and colour change.

Zooplankton.

a. Light and vertical distribution.

It has been known for many decades from observations on the habits of plankton animals that light is of importance in its effects on behaviour. Most plankton animals show in the laboratory very distinct tropistic responses by moving to or from the source of the stimulating factor. This is especially obvious in their responses to light, the organisms being either positively or negatively phototrophic. An immense amount of study has been given to this problem (see, e. g. Spooner, 1933) and it has often been stressed that the intensity and composition of light were important controlling factors.

In 1926 I indicated the apparent importance of light intensity in the sea by bringing to notice certain similarities in the vertical distribution of plankton animals with the theoretical behaviour that might be deduced from a knowledge of the light conditions. This had been stimulated by the pioneer observations being made then by Poole

and Atkins, and was based on a comparison between their results and the behaviour that I had found by field observations. Although it had been realized by many that the strength of light was evidently a factor of great importance, this was the first attempt to correlate behaviour with the actual results of the measurement of submarine illumination. This was followed in the next year by a review (Russell, 1927) summarizing our knowledge of the vertical distribution of plankton animals and the theories in which light had been considered as a factor by past workers. Since that date much attention has been given to this aspect of the problem and the literature on the subject has increased considerably. The evidence for the importance of light in affecting the behaviour of plankton animals is now overwhelming and it is manifested by the following facts.

i. The periodic migrations of many animals towards the surface in the dark, and downwards away from the highly illuminated layers in the daytime.

ii. The changes in the daylight vertical distribution of the same species of animal from day to day and place to place according to the illumination as affected by weather conditions and the opacity of the water.

iii. The fact that animals will migrate vertically according to light intensity changes during the 24 hours in spite of large vertical variations in the isotherms occurring at the same time.

This was suggested by Russell (1927, p. 241) as a crucial test to establish the major influence of light over temperature, and has been confirmed by Clarke (1934, a, p. 445; 1934, b, p. 537). For instance at St. 1722 on July 16th, 42° 50′ N. 67° 05′ W., in the morning all the isotherms were rising rapidly between 3 and 6 o'clock, that of 10° C. being displaced vertically during that time by some 12 metres, from about 26 m. to 14 m.; yet during the same time Calanus made an extensive downward migration with the increasing illumination.

The first simultaneous measurements of submarine illumination and the vertical distribution of the plankton were made by Atkins (Atkins and Poole, 1933) and Russell (1934) in the English Channel, and by Clarke (1933 and 1934, a) in the Gulf of Maine. These observations showed a certain amount of agreement between vertical movements of the zooplankton and changes in light intensity, but more work of this nature is desirable.

b. Physiological effects of light o plankton animals.

(i) Effects of intensity.

Welsh (1932) showed a correlation betwee the intensity of the light and the rate of swimmin of the larvae of the mussel crab, *Pinnothere maculatus*. (e. g. page 319).

Larvae 20 hours old. Temperature 24.5° C. ± 0.

Light intensity[1]) in metre candles.	Seconds taken to swim 29 cm. towards the light.
0.47	33.9
0.93	31.8
2.3	27.2
4.7	23.5
9.3	21.5
23.3	17.5
46.5	16.7
93.0	16.6

Similarly with the copepod *Centropages typicus* Welsh (1933) showed that increase of intensity led to an increased speed of locomotion. Centropages in intensities of 1394 metre candles swam 10 cm. on an average in 4.4 seconds, but at 0.7 metre candles they took 8.5 seconds to travel the same distance. He found, however, that this relation apparently did not hold true for animals moving by means of cilia.

Marshall, Nicholls and Orr (1935) exposed specimens of the copepod *Calanus finmarchicus* to daylight in ordinary clear glass bottles. They found that, while there was no apparent increase in activity, their oxygen uptake increased considerably. "In bright diffuse light, or in sunshine, the respiration may be even double what it is in the dark".

Experiments with Calanus in vessels submerged to different depths, however, showed that the light had an effect on respiration at the surface and 0.5 m., but hardly any at 5 m. and 10 m. This does not necessarily imply that light intensity beneath the sea surface is not an important factor in this respect. Calanus is a copepod which, compared with many other species, lives relatively high in the water. Deeper living species may consequently be strongly affected on entering the well illuminated layers above their normal habitat. At certain times of the year Calanus also is found swarming at the surface.

These authors also found that if Calanus are returned to the dark after exposure to light their respiration shows after a period of time a value much below that of the controls which had not been exposed. This suggested that the Calanus had been injured by the light.

[1])The light source was a 6-volt, 18-ampere, ribbon filament lamp. Intensity was controlled by means of Wratten neutral tint filters, and was measured with a Macbeth Illuminometer.

) Effects of different wave lengths.

A number of workers have shown the greater ver of one portion or another of the spectrum to ke a response to light stimulus in different mals. Some examples of the wave lengths to ich certain animals are most sensitive are given ow.

Larvae of the hydroid, Eudendrium, to blue (460—480 mμ)
Larvae of the worm, Arenicola, to green (*ca.* 495 mμ)
Larvae of the Squid, Loligo, to blue green (470—510 mμ)
Cyprid larvae of barnacles, to green (530—545 mμ)
(cited from Visscher and Luce, 1928, p. 348).

Harvey (1929) showed that the rate of heart t of Calanus decreases as injury is inflicted by ect sunlight. He found that the blue end of the ctrum was more effective in causing injury than green or red. Klugh (1929) in demonstrat- the lethal effects of the ultraviolet component sunlight found that with filters transmitting the raviolet the copepods *Calanus finmarchicus*, *tanus discaudatus*, and *Eurytemora herdmani*, re killed on the average in 36, 16.5 and 16 rs respectively. By contrast (Klugh, 1930) tain shallow water animals and a ctenophore ich lives very near the surface were found to be re resistant.

Lepeschkin (1931) found that if certain cies of copepods were exposed to direct sunlight ir resistance to poisons, such as mercuric oride, was decreased. Using *Paracalanus parvus*, *caea venusta* and *Euterpe acutifrons* he gives following survival times for different concen- tions of poison at 22° C.

$HgCl_2$	Survival time in minutes.	
	Kept in dark	Exposed to direct sunlight.
0.025	1.7	
0.0125	2.3	
0.006	3.8	
0.003	6.4	4.5
0.0013	10.8	7.5
0.00026	41.0	30.0

If however a filter (586-A by the Corning ss Company) was used cutting out the visible s and allowing only the ultraviolet to pass, it s found that the resistance of the animals was reased by 15 % if the exposure lasted not ger than 10 minutes. It was concluded "that ra violet rays protect the animals from the in- ious effects of visible light". But prolonged posure to ultra violet was naturally harmful. It may be therefore that occasional short excursions to the sunlit layers may thus have a beneficial effect on the organism in increasing its resistance to light.

The penetration of ultraviolet rays into the sea must have some significance in the production of vitamin D in the liver oils of fish. The ultraviolet rays are quickly absorbed, wave lengths of 303 mμ being reduced to 1 % at 2.1 m. and of 313 mμ to 1 % at 2.2 m. (Atkins and Poole, 1933, p. 161). Yet at times plankton animals are abundant actually in the surface waters and it is possible that on these occasions irradiation takes place (Russell, 1930). A slight antirachitic value has been shown by Drummond and Gunther (1934) for zooplankton oil.

c. Light in relation to zooplankton production and distribution.

The seasonal change in submarine illumination and its variations from year to year caused by weather conditions may have important effects upon the production of zooplankton. In northern temperate waters there is, for instance, a regular seasonal cycle of plant production characterized in many localities by a heavy vernal production of diatoms and a second smaller production in the autumn. But the amount of production and times of onset of these outbursts vary greatly from year to year, being dependent upon the illumination. There are also typical life cycles and brood productions among the different species of plankton animals. It can be realized that the extent to which brood production falls out of tune with the sequence of production of the plant food supply will decide the success or failure of a brood to survive. This is possibly a factor of great importance in the autumn months. Many species of animals produce, in August or September, their last brood of the year. The extent to which this brood will survive to form the stock for the breeding population in the following year must depend upon the supply of plant food. The autumn outburst of diatoms shows a considerable degree of variation, and is especially likely to be curtailed by inclement weather conditions since at that time of year the strength of the light is waning daily.

Recent work by Hardy and Gunther (1935) has brought into prominence the relationship between zooplankton and phytoplankton. Their results supply very strong evidence that in certain areas the animals may be positively excluded by excessive growth of diatoms. Since light intensity plays such an important part in the vertical migrations of plankton animals and since it controls plant production the bearing of illumination on the problems of horizontal distribution is obvious. The very fact also that production of the planktonic plant life is limited to

the upper illuminated areas must have a considerable bearing on the distribution and production of the fauna living in the dark depths of the ocean.

2. Bottom Fauna.

a. Light and the zonation of sedentary and bottom animals.

The intensity and spectral composition of the light are possibly important factors in determining the settling positions of a number of sedentary animals. This is especially the case among those animals which cause so much damage by fouling the bottoms of ships and other submarine structures. Many of the smaller bottom-living invertebrates also are probably limited in their distribution by that of the algae among which they dwell. In this respect the first actual measurements of submarine illumination in the sub-littoral zone have been made by Kitching, Macan and Gilson (1934). These authors made observations in connexion with a study of the sublittoral fauna on a rock surface in a gully in Wembury Bay on the coast near Plymouth. An illumination 1 % of that in air was found in the Laminaria forest at midday in August in water 3.7 metres deep.

The depth to which algae can grow on the bottom is also of importance in the distribution of the animals, and the measurement of bottom intensities in different localities and latitudes would be of value. It is of interest that Steuer (1935, pp. 11—13) has recently shown the presence of extensive fields of green algae in the Mediterranean off Alexandria, where Caulerpa may be found on the bottom in water up to 50 fathoms (91.5 m.) in depth, while red and green algae still occurred at 55 fathoms (100.6 m.).

Many animals carry within their tissues symbiotic algae whose growth and reproduction must depend upon the presence of sufficient light. Perhaps in no group of animals are these more prevalent than in the reef-building corals of the tropics. Although the exact relationship of these symbiotic algae to the animals within whose tissues they live is still under discussion it is evident that from their prevalence they must bear some vital relationship one to another. The work of Verwey (1930) and Yonge (e.g. Yonge, Yonge and Nicholls, 1932) on the physiology of corals has shown the necessity for having measurements of the submarine illumination at different depths in the various types of locality in which these corals live.

b. Physiological effects of light on bottom animals.

Bottom animals which live habitually in a world of low illumination are probably very sensitive to variations in intensity. It is possible that many species are purely nocturnal, retreating into burrows in the daytime. It has been shown by Welsh (1934, p. 343) that the worm, *Terebella*, if kept in the dark for ½ hour or longer will lie with its tentacles relaxed and fully extended. In this condition they are very sensitive to light and extremely low illumination results in rapid contraction and writhing movement.

Klugh and Newcombe (1935) have found indications that light intensity may be a factor in the growth of marine animals. A study of the barnacles, *Balanus balanoides*, growing on a wharf at St. Andrews, New Brunswick, showed that there was an increased rate of growth with a decrease in the amount of illumination. In three positions chosen with decreasing amounts of illumination the sizes of the barnacles 2 years of age were approximately 5 mm. in height by 6 mm. in width, 7 mm. by 7 mm., and 15 mm. by 9 mm., respectively. This possibility needs following up more closely and experiments should be made under controlled conditions, since so many factors such as food supply and wave exposure enter into the problem (cf. Moore, 1935 and 1936).

The possible relationship between illumination and the onset of maturity, that is now receiving attention in the study of birds and land mammals, should also be considered for marine animals.

3. Fishes.

a. Light discrimination.

Fishes possess the highest type of organ evolved for the detection of light, the eye, and it is natural that much research has been done to discover their powers of observation and colour discrimination. Recently Bull (1935), in his most careful studies on the perceptive faculties of fish by the conditioned reflex method, has shown that the blenny, *Blennius pholis*, possesses a wide range of colour vision. This is a fish that does not discriminate wide differences in intensity and it is therefore unlikely that the colour discrimination could have been an intensity effect. Such work indicates the need for a detailed knowledge of the spectral composition of light beneath the surface and its effects on the visual interpretation of colours as seen at different depths.

It is also possible that detection of differences in light intensity may play a part in the control of the migrations of some fishes. It is for instance notable that the tunny, *Thunnus thynnus*, migrating into the North Sea do not pass through the English Channel neither do they occur in numbers in the southern North Sea far south of about 54° N. latitude. It seems possible that the opacity of the silt laden waters of the eastern end of the Channel and the southern North Sea may be an effective barrier. The possibilities of the effects of artificial light in attracting or diverting fish should be considered. Tauti and Hayasi (1926) found that

light be projected at night vertically down-
ls into the water, fish swimming in numbers
er in the water are only attracted individually
e light when by random movements they swim
ards into a certain threshold intensity.
The vertical migrations of such fish as the
ng and the hake must also to some extent be
nction of the light intensity.

Physiological effects of light
nd colour change.

t has been suggested by Dannevig
2, a) that the number of vertebrae in the cod
be influenced in the early stages of develop-
by light. Fish reared in a shallow water
had a lower number of vertebrae than those
e open sea. He also drew attention (Danne-
1932, b) to the susceptibility of cod fry to
in the sea-fish hatchery.
Another manner in which illumination affects
s and other marine invertebrates is shown by
responses of colour change. The subject of
ur change has given rise to a big literature
two recent summaries by Parker (1930)
Sand (1935) may be mentioned. Light in-
nces the colour change both through the eye
directly on the skin surface. A knowledge of
intensities at which the different species nor-
y live is necessary; the adaptive function of
ur change in an environment in which illu-
ation is very low, and at which many colours
eliminated has to be taken into consideration.
k by Brown (1936) on the colour change
he minnow, *Ericymba buccata*, indicates an
tation to very low intensities. For instance the
age diameters of the melanin masses in fish
on a black background varied as follows:—

Light intensity metre candles.[1])	Diameter in μ.
0.00000046	43.1
0.0000049	43.4
0.000058	53.4
0.00116	59.2
0.023	67.9
0.163	78.3
2.21	78.0

n these experiments the sources of illumination
a 200 watt tungsten lamp, a 75 watt day-
Mazda lamp, and a 25 watt tungsten lamp
a daylight filter. The lowest intensities were
ined by means of an iris diaphragm and
ral light filters. Light intensity was measured
a potassium photo-electric cell with maximum
itivity in the blue end of the visible spectrum,
tructed by Professor J. Kunz.

[1]) converted from foot candles.

In the above pages I have attempted to collect together a number of observations dealing with various aspects of submarine illumination in relation to animal life. While not intended in any way as a comprehensive review of the subject sufficient indications should have been given to show how necessary it is to have a thorough knowledge of light conditions beneath the sea surface. This knowledge is essential before the biologist can attempt to relate behaviour observed under experimental conditions in the laboratory with the habits of the animals in the field. To this end there is great need for carefully controlled experiments in the laboratory in which conditions of illumination such as are likely to be found in the animals' normal habitat are used. The elaboration of technique and the advance of our knowledge of conditions in the sea make these aims much more obtainable than they were a few years ago, and the future should show an attempt to regard light as a factor in experimental work every bit as needful of control as temperature.

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References.

Atkins, W. R. G. and Poole, H. H. 1933. The Photo-electric Measurement of the Penetration of Light of Various Wave-lengths into the Sea and the Physiological Bearing of the Results. Phil. Trans. Roy. Soc. London, Ser. B., Vol. 222, pp. 129—164.

Brown, F. A. Jr. 1936. Light Intensity and Melanophore Response in the Minnow, *Ericymba buccata* Cope. Biol. Bull., Vol. LXX, No. 1, pp. 8—15.

Bull, Herbert O. 1935. Studies on Conditioned Responses in Fishes. Part III. Wave-length Discrimination in *Blennius pholis* L. Journ. Mar. Biol. Assoc., N. S., Vol. XX, No. 2, pp. 347—364.

Clarke, George L. 1933. Diurnal Migration of Plankton in the Gulf of Maine and its Correlation with Changes in Submarine Irradiation. Biol. Bull., Vol. LXV, No. 3, pp. 402—436.

Clarke, George L. 1934 a. Further Observations on the Diurnal Migration of Copepods in the Gulf of Maine. Biol. Bull., Vol. LXVII, No. 3, pp. 432—455.

Clarke, George L. 1934 b. Factors affecting the vertical distribution of copepods. Ecological Monographs, 4, pp. 530—540.

Dannevig, Alf. 1932 a. Is the Number of Vertebrae in the Cod influenced by Light or High Temperature during the Early Stages. Journ. du Conseil, Vol. VII, No. 1, pp. 60—62.

Dannevig, Alf. 1932 b. The Influence of Light on the Cod. Journ. du Conseil, Vol. VII, No. 1, pp. 53—59.

Drummond, J. C. and Gunther, E. R. 1934. The Vitamin A and D Content of Oils derived from Plankton. Journ. Exper. Biol., Vol. XI, No. 2, pp. 203—209.

Hardy, A. C. and Gunther, E. R. 1935. The Plankton of South Georgia whaling grounds and adjacent waters, 1926—1927. Discovery Reports, Vol. XI, pp. 1—456.

Harvey, J. M. 1929. The action of Light on *Calanus finmarchicus* (Gunner) as determined by its effect on the Heart rate. Contrib. Canadian Biol., Vol. V, pp. 83—92.

Kitching, J. A., Macan, T. T. and Gilson, H. Cary. 1934. Studies in Sublittoral Ecology. I. A. Submarine Gully in Wembury Bay, South Devon. Journ. Mar. Biol. Assoc., N. S., Vol. XIX, No. 2, pp. 677—705.

Klugh, A. Brooker. 1929. The Effect of the Ultra-violet Component of Sunlight on Certain Marine Organisms. Canadian Journal of Research, Vol. 1, No. 1, pp. 100—109.

Klugh, A. Brooker. 1930. The Effect of the Ultra-violet Component of Sunlight on certain Aquatic Organisms. Canadian Journal of Research, Vol. 3, pp. 104—106.

Klugh, A. Brooker and Newcombe, Curtis L. 1935. Light as a Controlling Factor in the Growth of *Balanus balanoides*. Canadian Journal of Research, Vol. 13, Sec. D., No. 3, pp. 39—44.

Lepeschkin, W. W. 1931. Some Experiments on the Influence of Light and Poisons on Marine Copepods, with reference to their Daily Migration. Bull. Scripps Inst. Ocean., La Jolla, Tech. Ser., Vol. 3, No. 2, pp. 33—35.

Marshall, S. M., Nicholls, A. G. and Orr, A. P. 1935. On the Biology of *Calanus finmarchicus*. Part VI. Oxygen Consumption in Relation to Environmental Conditions. Journ. Mar. Biol. Assoc., N. S., Vol. XX, No. 1, pp. 1—28.

Moore, Hilary B. 1935. The Biology of *Balanus balanoides*. IV. Relation to Environmental Factors. Journ. Mar. Biol. Assoc., N. S., Vol. XX, No. 2, pp. 279—307.

Moore, Hilary B. 1936. The Biology of *Balanus balanoides*. V. Distribution in the Plymouth Area. Journ. Mar. Biol. Assoc., N. S., Vol. XX, No. 3, pp. 701—716.

Parker, G. H. 1930. Chromatophores. Biological Reviews, Vol. V, No. 1, pp. 59—90.

Russell, F. S. 1926. The Vertical Distribution of Marine Macroplankton. IV. The Apparent Importance of Light Intensity as a Controlling Factor in the Behaviour of Certain Species in the Plymouth Area. Journ. Mar. Biol. Assoc., N. S., Vol. XIV, No. 2, pp. 415—440.

Russell, F. S. 1927. The Vertical Distribution of Plankton in the Sea. Biological Reviews, Vol. II, No. pp. 213—262.

Russell, F. S. 1930. Vitamin Content of Marin Plankton. Nature, September 27, 1930.

Russell, F. S. 1934. The Vertical Distribution of Marine Macroplankton. XII. Some Observations on th Vertical Distribution of *Calanus finmarchicus* in Rel tion to Light Intensity. Journ. Mar. Biol. Assoc., N. S Vol. XIX, No. 2, pp. 569—584.

Sand, A. 1935. The Comparative Physiology of Colou Response in Reptiles and Fishes. Biological Review Vol. X, pp. 361—382.

Spooner, G. M. 1933. Observations on the Reactio of Marine Plankton to Light. Journ. Mar. Biol. Assoc N. S., Vol. XIX, No. 1, pp. 385—438.

Steuer, Adolf. 1935. The Fishery Grounds nea Alexandria. I. Preliminary Report. Fisheries Researc Directorate. Egypt. Notes and Memoirs, No. 8, pp 1—16.

Tauti, M. and Hayasi, H. 1926. On the Shoal o Fishes crowding toward a Lamp. Journ. Imper. Fish Inst. Tokyo, Vol. 21, No. 4, pp. 42.

Verwey, J. 1930. Depth of coral reefs and penetratio of light. With notes on oxygen consumption of corals Fourth Pacific Science Congress, Batavia-Bandoeng (Java), May-June 1929, pp. 1—23.

Visscher, J. P. and Luce, R. H. 1928. Reactions of the Cyprid Larvae of Barnacles to Light with Specia Reference to Spectral Colours. Biol. Bull., Vol. LIV No. 4, pp. 336—350.

Welsh, John H. 1932. Temperature and Light as Factors influencing the Rate of Swimming of Larvae of the Mussel Crab, *Pinnotheres maculatus* Say. Biol. Bull., Vol. LXIII, No. 2, pp. 310—326.

Welsh, John H. 1933. Light Intensity and the Extent of Activity of Locomotor Muscles as opposed to Cilia. Biol. Bull. Vol. LXV, No. 2, pp. 168—174.

Welsh, John H. 1934. The Structure and Reactions of the Tentacles of *Terebella magnifica* W. Biol. Bull., Vol. LXVI, No. 3, pp. 339—345.

Yonge, C. M., Yonge, M. J. and Nicholls, A. G. 1932. Studies on the Physiology of Corals. VI. The Relationship between Respiration in Corals and the Production of Oxygen by their Zooxanthellae. Great Barrier Reef Expediton 1828—29. Scientific Reports (British Museum) Vol. I, No. 8, pp. 213—251.

2.

THE PHOTO-ELECTRIC MEASUREMENT OF SUBMARINE ILLUMINATION IN OFF-SHORE WATERS.

BY

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DUBLIN.

Introduction.

A knowledge of the solar radiation at different depths and under various conditions may be of importance to the oceanographer for several reasons. The temperature distribution in the upper layers may evidently be affected by the intensity of the total radiation of all wave-lengths, while the rate of photosynthesis is largely governed by that of wave-lengths in or near the visible spectrum. This region includes all those wave-lengths which possess sufficient penetrating power to reach appreciable depths, so that, whether we are interested in the visibility of under-water objects, the rate of photosynthesis, the effect of radiation on the movements of marine organisms, or the warming of the water at moderate depths, we must attach primary importance to measurements in this part of the energy spectrum. Hence measurements of submarine radiation are generally considered as measurements of illumination, though, as the visual effects are seldom of importance, it is desirable that the results should be given, if possible, in energy units, as has been done by Clarke (4).

A related problem has been the opacity of the water. This gives a measure of the total suspended matter present and, as Clarke (4) has shown, may be of great use in tracing the movements of oceanic waters. A measure of the opacity may be obtained from the vertical rate of decrease of daylight illumination, though an alternative method developed by Pettersson (7) has much to recommend it, especially for inshore, and therefore highly heterogenous, waters.

Birge and Juday (2) have used a thermopile with suitable colour filters to measure the penetration of radiation in lakes, but the use of such a method at sea presents certain difficulties, and most measurements are now made by means of some form of photo-electric cell.

Shelford and Gail (15) were, so far as I know, the first workers to use emission photoelectric cells to measure submarine daylight. Their measurements were carried out with Kunz gas-filled potassium emission cells in Puget Sound, where the water was smooth enough to allow a sensitive galvanometer to be used to measure the current. The publication of Shelford's first paper encouraged Atkins to initiate similar investigations near Plymouth, and modified methods were developed to suit the different conditions. Since then a number of workers have used photo-electric cells of various types. I propose to limit myself to the consideration of some of the problems involved in the measurements, paying especially attention to those arising out of the work of my colleague Dr. Atkins and myself in the English Channel. Most of these problems have been dealt with at some length in the literature of the subject, but as the references are somewhat scattered, I hope that a summary may be of interest to those who may desire to make similar measurements. The numbered references indicate papers in which further details may be found.

Types of Photo-electric Cell.

When Shelford and Gail commenced their measurements the only cells available possessing sufficient sensitivity for work at considerable depths were of the gas-filled thick-film emission type. We also used these cells in much of our early work. When suitable precautions are taken, including frequent comparisons of the sensitivity with that of a vacuum emission cell, it is possible to make reasonably accurate measurements, but the use of a cell whose constancy can be relied upon simplifies the work greatly.

Vacuum thick-film emission cells are much less sensitive than gas-filled cells of the same size, but the older type of unsensitized potassium cell made by the General Electric Co. and the sodium cells made by Dr. Burt appear to maintain their sensitivity indefinitely, even in full daylight. Moreover, small variations in the potential of the battery used are comparatively unimportant, provided that this is high enough to ensure approximate saturation. Sensitized thick-film vacuum cells are more sensitive, but apparently less stable, than the unsensitized type (4).

The above sodium and potassium cells are only sensitive to wave-lengths below about 500 mμ. The first cell which we found suitable for measurements in other parts of the visible spectrum was the caesium monomolecular vacuum C. M. V. 6 cell made by the General Electric Company. This is considerably more sensitive than the early types, and, being sensitive throughout the whole visible spectrum, can be used with suitable filters to measure the penetration of light of all colours. Its sensitivity has, however, fallen in the course of some years to less than half its original value. Various other very sensitive vacuum emission cells have since appeared, some of which, such as Bolton King's X 16 type made by the Oxford Instrumental Co., are specially sensitive in the red and near infra-red, and so might be very useful for experiments in that region.

It is probable, however, that in future most under-water measurements will be made with some form of selenium rectifier cell such as used by Pettersson and Landberg (6), by Utterback and Boyle (16), by ourselves (11), and by others. With such a cell no external source of E. M. F. is needed, the illuminated cell acting as battery. Our experience has been chiefly confined to the Bergman type Weston Photronic Cell, which we have found to possess the great virtue of constancy over a number of years (14).

The advantages of the selenium cell may be summarised as follows:—

(a) Its great sensitivity renders the currents to be measured comparatively large.
(b) The absence of any high potentials greatly simplifies insulation problems, and facilitates the measurement of small currents in damp weather.
(c) The compactness of the cell enables a smaller and lighter photometer case to be used.
(d) As the sensitivity curve is much nearer to that of the eye than that of any emission cell, the cell when used without colour filter agrees reasonably well with the eye in its rating of illuminations of different predominant colours.

On the other hand, the use of these cells introduces certain complications, which must not be overlooked if accurate results are required (12).
(a) The current is not accurately proportional to the light if the latter is intense. A correction must accordingly be introduced for the curvature of the current/illumination characteristic. This "curvature" correction may be found from photometer-bench measurements using a small and brilliant source, such as a filament projection-type lamp run at constant voltage, to obtain the desired intensity. With our cells and low-resistance measuring circuits the curvature correction with the cell under opal-flashed glass in full sunlight is about 20 %.
(b) This curvature correction rapidly increases in importance as the resistance of the measuring circuit is increased. Thus, if a galvanometer resistance as high as 100 ohms is employed the illumination must be kept down to a small fraction of full sunlight by the use of suitable screens when the photometer is near or above the surface. Even then the correction is likely to be large, and the extra complication of the absorbing screens is objectionable.
(c) The cells are affected by temperature in a somewhat complex way, becoming slightly more sensitive for weak illuminations and less sensitive for high illuminations if the temperature rises. This effect also increases greatly with increase of resistance, the error caused by exposure of the cell under opal diffusing glass to full sunlight being apparently negligible provided that the galvanometer resistance does not exceed 10 ohms.

Measurement of the Photo-electric Current.

Several workers have found it possible to use special types of sensitive galvanometers afloat, and thus gain the advantages of a direct reading. This is especially valuable when it is desired to measure the mean value of a rapidly fluctuating illumination, such as occurs just below the surface, for which purpose a telephone balance is rather unsatisfactory. Since, however, it is difficult to combine the galvanometer sensitivity needed for low illuminations, such as occur under colour filters in comparatively deep water, with the low resistance required for high ones, special care must be taken to avoid the errors mentioned above or separate instruments must be used for deep and shallow water (16). Since a very wide range of illumination must be covered some form of shunt is essential, and a constant-resistance shunt is convenient (12).

Under the conditions of our own measurements the motion of the ship is generally so violent that we have never thought it worth while to attempt to use a galvanometer so that I cannot speak from experience of the behaviour at sea of the special types of instrument used by other workers. We have adopted a combination of the potentiometer-interrupter-telephone method, which we have always used with emission cells (1), with the special zero-resistance circuit first described by Campbell and Freeth for use with rectifier cells. (3 and 13).

In Campbell and Freeth's circuit, as shown in Fig. 1, the potential divider P is adjusted until the sensitive galvanometer G which is connected across the terminals of the rectifier cell C reads zero. All the current passing through C now passes through the microammeter, M, by which it is measured. It will be noticed that since the terminals of the cell C are brought to the same

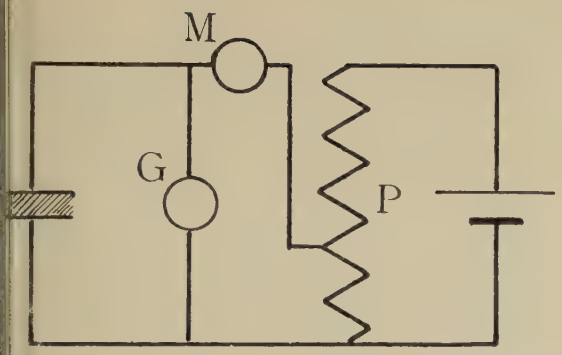

Fig. 1.

ntial the arrangement acts as a galvanometer ero resistance, no matter what the resistance of nd *M* may be.

For use at sea we have replaced *M* by a able known resistance *R*, which may have any ue from 100 to 100,000 ohms (See Fig. 2.). current through this is found from the re- ance and the setting of the standard potentio- er *P*, which is here used as a source of variable ntial. The null-point indicator, *G*, is replaced the rolling wheel interrupter, *I*, amplifier, *A*, telephones, *T*, which we have used with emis- cells. The switch, *S*, is used to cut out and rt-circuit the photo-cell when the potentiometer eing set against its standard source of potential t shown in the diagram), the interrupter- lifier-telephone being also used for this pur- e. The arrangement constitutes a zero-resistance suring instrument, readily capable of measur- currents between 10^{-9} and 10^{-2} ampere (or larger if required), and enables rectifier cells e used at sea for the measurement of very ll illuminations.

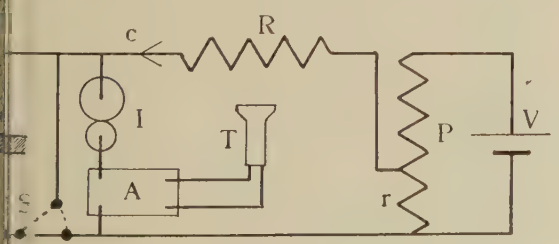

Fig. 2.

There are two disadvantages which must be embered. In the first place since the potentio- er itself is used at an unbalanced setting, so a current is passing across the sliding con- s, the resistance of these contacts, and of rs in the potentiometer switches, may cause an r if the surfaces are not kept clean. A little e, however, and the use of a little vaseline on the surfaces will ensure that this is negligible, if *R* is not less than 100 ohms. Secondly, the current flowing is less than the apparent value *E*/*R*, where *E* is the potentiometer reading, by an amount depending on the values of *E* and *R*, and the total potentiometer resistance. In our arrangement the factor by which the apparent current must be multiplied to correct for this effect lies between 0.90 and 1.00. It is convenient to plot curves so that the value can be read off instantly (13). It is worth noting that this correction is opposite in sign to the "curvature" correction for a rectifier cell, and usually of about half the magnitude of the latter.

Marine Equipment.

The submerged cell must obviously be protected by enclosure in a water-tight metal case strong enough to withstand any pressure that it may experience, and the somewhat rough handling that it may receive in bad weather. This is slung by a bridle so that the window in the top of the case is horizontal. This window should be appreciably larger than the cell and strong enough to stand the hydrostatic pressure. For work with the Weston selenium cell we have used a circular plate glass window 6 mm. thick, the aperture being about 7.6 cm. in diameter. The cell is mounted just beneath the window. The joint is made with a rubber gasket and "Sira" soft wax, the circular brass run by which the window is clamped being thick enough to hold in place the opal-flashed diffusing glass and any colour filter used. These are laid on the window, the opal glass being on top, and prevented from falling off, in the event of the photometer being inverted, by three clips attached to the brass run.

It is most important that the possibility of light reaching the cell round the edges of the colour filter should be prevented, as with a heavily absorbing filter a small percentage of unfiltered light will cause a relatively large error.

For a rectifier cell a round tough-rubber-covered twin flex of good quality makes a satisfactory pair of leads. This may enter the photometer case through a projecting tube, the joint being made with a stout rubber sleeve. This simple arrangement seems to be as reliable as the screw glands which we used with separate high tension ignition cable leads for emission cells.

Great care must be taken with all joints, as the entry of water under pressure might ruin the cell. It is rather a good plan to use a cell case somewhat deeper than the cell, so that some space is available below it in case a small amount of water leaks in. By bringing the bared leads into this space we may obtain warning of any leak, as the short-circuiting of these wires by salt water would almost certainly be detected. This could be rendered even more noticeable by using short

lengths of dissimilar metals, one in each lead, so that in the presence of water a small galvanic cell would be formed.

Pettersson (6) has used a somewhat similar arrangement, but Utterback (16) has devised a more elaborate photometer case with an internal set of colour filters instantly interchangeable by an electrically operated device. This must have great advantages in use, though the increased size of the case and the thicker electric cable needed for the additional circuit might cause larger drift errors in strong winds. With emission cells using an external source of potential a shutter to test the "dark current" is almost essential, but this is unnecessary with rectifier cells.

The supporting wire cable must evidently be strong enough to bear any load that may be brought upon it by the motion of the ship, but it should not be unnecessarily stout since this increases the error due to drift. This is discussed later. The cable passes through a pulley attached to a spar projecting over the stern, so that the rolling of the ship does not affect the depth of immersion. Pitching, however, limits the length of spar that can profitably be used, and our photometer is suspended from a point about 2 m. clear of the end of the ship's counter. Even in this position the vertical motion may be considerable — say 1 to 2 metres in bad conditions. The resulting variation in illumination is especially objectionable near the surface. If the photometer is hoisted clear of the surface rolling may cause it to swing, so that its reading fluctuates widely. For these reasons measurements of surface loss are always unreliable in bad weather.

It is convenient to measure the depth by means of a meter pulley the sheave of which should be so large that small variations in the diameter of the cable used are unimportant; in our case the circumference equals one metre.

Optical Considerations.

The optical conditions affecting the reading of a photo-cell exposed in air or water merit some consideration (1). We cannot expect two photometers to give the same ratio for the illuminations at two points (even for monochromatic light) unless either (a) the relative angular distribution is identical at the two points, or (b) the relative angular sensitivity curves of the photometers is the same. Thus, photometers with "wide-angle" and "narrow-angle" sensitivities would give different relative intensities at different depths if the average angular distribution of the submarine illumination varied with the depth — a point to be borne in mind in comparing the results obtained by different workers, although, as we shall see later, there is reason for supposing that this variation in obliquity with depth is small.

It is generally convenient to measure the daylight illumination at a given point by the li falling on a plane horizontal surface freely expos to the entire upper hemisphere. The Weston ce which we use suffer appreciable shading of lo angle light by the rim of the case, and this shadi is almost certain to be increased for the c mounted in the submarine photometer. Moreov one would not be justified in assuming witho test that the response of the cell to a beam light varies as the cosine of the angle of inciden We have accordingly always mounted our ce behind freely-exposed opal-flashed glass, as us for emission cells (for which angular anomali are generally even more important).

Since the diffusing properties of a roughen glass surface are greatly reduced by immersion water this glass has polished surfaces, the diffusi layer being internal. Reflection-losses at the upp surface above the diffusing layer reduce the se sitivity by a calculable amount for low-angle lig (8). When this correction has been applied th reading of a cell behind such a diffusing she illuminated by a small source is very nearly pr portional to the cosine of the angle of incidenc of the beam, so that such a combination, mounte horizontally, may be used to measure the vertica component of daylight as defined above.

In our submarine photometer the diffusin glass is immersed in the water, and is affected b light coming from any angle appreciably abov the horizontal. When the photometer is bein compared with our standard cell in air the smal space between the diffusing glass and the windo is filled with water, so as to obviate changes in th reflecting properties of these two surfaces on im mersion. The presence or absence of a shallo layer of water over the diffusing glass makes littl difference, as, although the total loss of inciden light at air-water and water-glass surfaces is les than at a single air-glass surface, this is compen sated by a small increase in the loss of back scattered light due to the water layer, as explained below.

When colour filters are employed they must be placed under the diffusing glass, so as to ensure that they are always used in light of constant obliquity. The spaces above and below the filter are filled with water during comparisons with the standard.

If the diffusing surface were omitted, or if it were placed in the air space inside the window any light in the water making an angle greater than 48.5° with the vertical would undergo total reflection at the inner surface of the window, and would not affect the photometer.

Immediately below a smooth water surface the illumination coming from above is also limited within the same solid angle, as may be qualitatively observed by looking upwards when swimming under water. Below a rough water surface, however, a variable proportion of the light makes a

ger angle with the vertical and could not affect photometer with a clear window. This may lain the considerable surface losses found by e workers under such conditions.

We must remember when comparing the lings above and below a water surface of a tometer with an external diffusing glass that immersion of the upper surface of the latter he water greatly reduces the reflection of light that surface. The effect of this is two-fold, there is less loss of incident light when the tometer is submerged, and (b) when the photo- er is in air much of the light scattered back by internal diffusing layer strikes the upper surface n angle of incidence greater than the critical e, 41.5°, for a glass-air surface, and so under- total internal reflection, returns to the using layer, and contributes to the illumination he latter and, hence, to the reading of the tometer. When the surface is immersed in er the critical angle is greatly increased, and t of the light escapes without contributing her to the reading of the photometer, unless water is so shallow that the light totally ected at the water-air surface can again enter photometer.

These two effects are opposed, and experiment shown that under the conditions of our work latter is the more important, so that the net lt is to decrease the sensitivity of a submerged ometer. To correct for this we multiply the ing of our immersed photometer by 1.09.

Measurement of the Surface Light.

t is evidently necessary to measure the surface hination along with that under water, and w for any changes that may occur. For this use our standard Weston cell mounted on als and covered with opal-flashed glass. This is exposed on the deck-house roof in a ion chosen so as to be as free as possible the effects of shading by the mast and ng. It was standardised against an artificial n noon-sunlight" source obtained in accord- with the specification of the Seventh Inter- nal Congress of Photography by means of a ent lamp at a colour temperature 2360° K specified liquid colour filters (5). The ant thus obtained agrees almost perfectly that found by comparison in average mixed ght with our standard potassium vacuum ion cell standardised against a carbon arc. agreement is fortunate, since no change is d in our old scale of values for mixed ght, though the rectifier cells, measuring to d both ends of the visible spectrum, naturally sunlight higher, and blue sky lower, than our lue-sensitive cells.

For most purposes it is desirable to be able to give the results of our measurements in absolute energy units instead of using units which are strictly applicable only to visual observations. This has been done by C l a r k e, and we have recently standardised in this way combinations of our standard cell with various colour filters. Special precautions and corrections must be used if serious errors are to be avoided in this method of standardisation, but the details of these, a consideration of which Dr. A t k i n s and I hope to publish shortly, would occupy too much space to be dealt with here.

It is generally most convenient to give the results of submarine measurements as percentages of the light in air. For this purpose the scale employed is immaterial. As daylight is often very variable a rapidly alternating series of readings of the two photometers must be made at each depth. The cells, and any filters used, should be as similar as possible in their characteristics, the filter on the standard "deck photometer" also being placed under the diffusing opal.

The readings of the two photometers must evidently be compared side by side in air. With a cell such as the selenium rectifier, whose sensitivity is constant, this is best done on shore, or at least in harbour, as, unless the submarine photometer is also placed on gymbals any rolling motion will cause its reading to vary, and render comparison difficult. With an inconstant cell, such as a gas-filled emission cell, the comparison must be effected immediately before and after each submarine series.

Colour Filters.

It is generally desirable to use a colour filter with a cell, such as the selenium rectifier, sensitive to a large part of the spectrum. It is not easy to obtain a set of filters which combine the necessary permanence and mechanical properties with high transmission in the desired spectral regions, each bounded on either side by a sharp "cut-off", and very low transmission for other wave-lengths. Thus, many blue and green filters pass varying amounts of deep red and infra-red, which may affect the selenium cell to an extent sufficient to cause serious error in the interpretation of the results.

The filters that we have so far found most generally useful are the Schott and Gen R G 1 and B G 12, for red and blue light, respectively, and the Corning Green for green light. The latter, which is 5 mm. thick, absorbs rather heavily even in the green, so that the sensitivity is reduced. A thinner filter might transmit too much infra-red.

The Schott and Gen filter R G 7 may be used with the selenium cell for the region just beyond the red end of the visible spectrum. Greater

sensitivity would be obtained in this region, however, by the use of King's X 16 type emission cell.

With a photometer such as that used by Utterback (16), in which the filters can be instantly interchanged, a differential system of working is possible. This would enable use to be made of the series of Schott and Gen filters, such as RG8, RG5, RG2, RG1, OG2, GG11, GG7, GG5, and GG3, each of which transmits freely from a limit in the far infra-red to a sharp cut-off in the visible spectrum. We may measure the radiation in the band between the short-wave limits of any two filters by the difference between the corresponding readings. This differential method, however, reduces the accuracy of the results, and it would be better to avoid it, if possible. It is evidently of very limited value with a photometer, such as ours, which must be hoisted on deck whenever a filter needs to be changed.

Errors caused by the Drift of the Ship.

It may not be convenient to anchor, in fact in deep water, as in Clarke's work, it would be impossible, and to do so in a tidal current would be no advantage from our present point of view. It is generally best to let the ship lie broadside to the wind with her stern in whichever direction is nearest to the azimuth of the sun. In strong winds, however, the drift will be rapid, and we must guard against the possibility of serious errors arising from the following causes. (a) Deviation from the vertical of the suspending cable which is also used for measuring the depth; this causes over-estimation of the depth, and, since the rate of drift is rarely constant, may seriously affect the vertical extinction coefficient found from two readings nominally at 10 metre intervals. (b) Deviation of the photometer window from the horizontal; this is certain to occur if the electric cable is not attached to the top of the bridle from which the photometer is suspended, so as to prevent the drag on it from tilting the photometer. (c) Horizontal variation in the opacity of the water; if between two measurements at different depths the ship drifts into water of different average opacity, it is evident that the vertical extinction coefficient found from the ratio of the two readings will be erroneous.

The first effect is minimized by the use of as thin supporting and electric cables as are consistent with adequate strength and insulation, and as small a photometer case as possible. A lead sinker should be attached to the latter (in such a way as to cause no tilting of the window) if the case itself is not heavy enough to keep the supporting cable within a few degrees of the vertical.

In strong winds the deviation may increase above this limit when working at depths greater than 10 m., or so. It is well to estimate as accurately as possible the mean deviation of the supporting cable from the vertical, but it is not easy to estimate with certainty the resulting error in the depth.

If the supporting wire rope itself offered the resistance to the lateral motion through the water, all the drag being due to the photometer case and the electric cable attached near the lower end of the supporting wire, the wire would remain straight, so that the actual depth would be $h \cos \theta$, where h is the apparent depth and θ is the deviation of the supporting wire from the vertical as observed above the surface.

If, on the other hand, the supporting wire were responsible for the entire drag it would take up a curve not very different from a circular arc, the lower part just above the photometer being vertical. It is easy to see that, in this case, the true depth would be $h \sin \theta/\theta$, where θ is in radians.

To a first approximation we may write $\cos \theta = 1 - \theta^2/2$ and $\sin \theta/\theta = 1 - \theta^2/6$ so that the depth error lies somewhere between $h\ \theta^2/2$ and $h\ \theta^2/6$, its value depending on the relative latera resistances of the supporting wire and of the photometer with electric cable (and sinker, if used). If we use the mean value $h\ \theta^2/3$ as a suitable approximation, the depth error amounts to 1 % for an inclination of 10°, 4 % for 20°, and so on. Thus with $\theta = 20°$ the error at 50 m. would amount to 2 m. Since θ increases with h, the error becomes much more important as the depth is increased, and, by reducing the actual intervals between levels, apparently equidistant, by amounts which increase with the depth, decreases the apparent opacity of the deeper water.

Shading due to the Ship.

Since, owing to pitching motions, we cannot suspend the photometer more than a couple of metres outboard, shading by the ship is certain to cause appreciable errors, which are hard to estimate with accuracy. It is easy to prevent shading of direct sunlight, so that the error increases with the proportion of diffuse light.

We may make a crude, but perhaps useful, attempt to estimate the maximum effect as follows. Since the light in perfectly clear water below a smooth surface is limited to within an angle $\sin^{-1} 1/n$ of the vertical, where n is the refractive index of the water, we easily find that the area of such a surface sending light to a point at a depth h metres is very close to $4.0\ h^2$ sq.m., the radius being about $1.13\ h$. From the dimensions of the ship, and the distance outboard of the point of suspension, we can estimate the proportion of this surface area that is occupied by the ship for any given depth, treating the overhanging counter as if it were submerged. We shall probably make no large error by assigning equal importance to each

are metre of effective surface, since the ship, nding radially, occupies a fairly representative n, so we can thus find the fraction of the use light that is cut off by the ship.

The above method underestimates the shading sed by the counter at small depths; thus it kes the shading zero at any depth less than .13, where a is the outboard distance of the nt of suspension measured from the end of the nter, while actually the counter and bulwarks t cause appreciable shading even at the surface. estimate of the solid angle subtended by the 's hull when the photometer is on the surface icates that this must amount to about 8 % for use light. The shading caused by the spar porting the photometer, and the ship's boom, hich it is lashed, is probably not very different n that caused by mast, spars, and rigging for photometer on the deck-house roof, and so may neglected. At a depth of 5 m., or over, this ve-water shading is probably negligible, since, ough the treatment of the counter as being merged underestimates its effective length, it r-estimates its width. as viewed from the sub- ged photometer. Thus we obtain the following nate for the shading by our ship in diffuse t.

Depth m	Shading Error %
0	8
5	10
10	6
15	4.5
20	3.5
25	2.5
30	2
35	1.5
40	1
45	1
50	1
55	0.5
60	0.5
65	0.5
70	0.5

right sunlight, as only the diffuse light is ted by shading, the error would only be about o $^1/_6$ as great, depending on the altitude and sity of the sunlight and the colour-sensitivity he cell and filter.

The importance of this error has been pointed by several workers. So far as I know, however, ttempt has hitherto been made to estimate its nitude. The above estimate for the particular itions of our own work can only be regarded n indication of the probable magnitude of the r due to this cause. We have not, as yet ap- l it to any of our measurements.

Accuracy obtainable in Submarine Measurements.

This is chiefly limited by the weather. On a calm cloudless day the surface light is steady, the shading error due to the ship is small, and the depth of immersion nearly constant, and measureable to within about 0.1 m. Under these circumstances there seems to be no reason why an accuracy of 1 % should not be attained for each reading.

It is very different in bad weather. With a strong wind and clouded sky the light is rarely constant, even though no sun is visible, while, if clouds and clear sky follow each other across the sun the light may drop to a small fraction of its value, or increase several times, in a few moments. A dull sky, even if uniform, increases the shading error, while pitching and drift of the ship render the depth of immersion variable and uncertain. Moreover, the personal discomfort caused by the rolling of the ship, and the sundry noises inevitable under such circumstances render difficult the attainment of an accurate telephone balance. Rapid variations of depth of immersion due to pitching are especially objectionable with the telephone method, as it is an added task for the observer, whose attention is centred on the telephone, to note at what phases of the ship's motions the silence that betokens balance is attained. If any galvanometer exists which combines the requisite sensitivity and low resistance with ability to function in a small vessel rolling heavily, its use under such conditions would be highly advantageous.

Measurements within a few metres of the surface are particularly difficult in rough weather, as light variations due to waves passing over the photometer must be added to those caused by the motion of the ship. At moderate depths the total variations become less important, so that measurement is much easier, though, as we have seen, drift errors increase.

Since it is only in exceptionally clear water that blue or green light decreases by less than 10 % per metre, while both longer and shorter wave-lengths are extinguished much more rapidly, there is evidently not much use in attempting to measure the light to much closer than 10 %, in conditions under which we may have an error of a metre in our estimated depth.

In view, however, of the enormous range of illumination covered by most series of under-water measurements, an error even so large as 10 % is rarely of great importance. Thus it is not likely to matter very much whether, on a rough day, a certain percentage of the surface light is attained at 30 m. or at 31 m., between which two levels the average illumination is likely to vary by at least 15 %.

Attainable Ranges of Illumination and Depth.

In many places the maximum depth of working is limited only by the bottom. Thus at International Station E1 in the English Channel, we have been able to measure the blue light with a gas-filled potassium cell down to 70 metres, which must be close to the bottom, the percentage of the surface light at this depth varying, on different occasions, between 0.016 and 0.12. The latter figure is about the limit attainable with our vacuum, unsensitized, thick-film potassium cell, which we have not used below 40 m.

In the Sargasso Sea Clarke (4), using a vacuum, sensitized, thick-film potassium cell worked as deep as 180 m., where the illumination was about 0.025 %, and in another series recorded over 0.5 % at 170 m. Shelford, also has attained considerable depths with emission cells.

It is probable, however, that, for measurements at extreme depths, rectifier cells will prove their superiority. Thus Utterback (17), in the course of a very complete investigation of the penetration of light of different colours in the N. Pacific, was able to work down to over 70 m. with a rectifier cell and colour filters, using a galvanometer to measure the current. At that depth the percentage of green light was in the neighbourhood of 0.5. If we use the potentiometer method of measuring the current, we should readily be able to measure a current of 10^{-8} ampere to within 10 %, with our existing amplifier. It is probable that a considerable gain in sensitivity could be achieved with more modern apparatus. For our standard Weston cell under opal glass 10^{-8} amp. corresponds to about 0.15 lux, i. e. about 0.015 % of full daylight. Of course the use of such a cell without colour filter will give a much lower percentage for the illumination in deep water than will a potassium cell, since much of the surface radiation to which the rectifier cell is sensitive is absorbed far more rapidly than the blue light which chiefly affects the potassium cell. The use of a filter to restrict the sensitivity of the rectifier cell to blue light is likely to reduce its sensitivity to about 15 % in daylight. On the other hand, we could double the sensitivity by omitting the diffusing glass (as Utterback apparently does).

It seems probable, then, that the ultimate sensitivity of a cell such as the Weston selenium cell which we have used is sufficiently high for most practical purposes, and that its use will avoid most of the uncertainties inherent in the employment of a gas-filled emission cell at high sensitivities.

Measurement of the Opacity of the Water.

Since the absorption of monochromatic radiation in a homogeneous medium follows the exponential law it is convenient to measure the opacity of the water for any given wave-length by means of the equation $I_2 = I_1 \, e^{-\mu (h_2 - h_1)}$ where I_1 and I_2 are the illuminations on a horizontal surface at vertical depths h_1 and h_2 metres, respectively, and μ, what we have always called the "Vertical Absorption Coefficient", measures the mean opacity of the intervening layer of water for the given wave-length. Pettersson's term "Vertical Extinction Coefficient" is certainly preferable, since much of the loss of light is due to scattering as distinct from true absorption.

For purposes of calculation we write the equation

$$\mu = \frac{2 \cdot 3 \, (\log I_1 - \log I_2)}{h_2 - h_1} = \frac{2 \cdot 3 \, (\log p_1 - \log p_2)}{h_2 - h_1}$$

where the logarithms are to the base 10 and p_1 and p_2 are the percentages of the surface light. The coefficient evidently measures the relative extinction per metre, thus a value 0.10 corresponds to a fall of illumination of 10 % per metre.

In order that we may use the vertical extinction coefficients thus defined as measures of the true opacities of the water in different layers it is evident that (a) the wave length and (b) the average obliquity of the light must be as nearly as possible the same. Thus, a selenium rectifier cell without filter will, in homogeneous water, give much lower values of μ in the deeper layers, where the highly absorbable red rays have been greatly reduced, than it gives for similar water near the surface.

This effect can be greatly reduced by the use of filters to limit the sensitivity of the photometer to comparatively narrow spectral bands, or by the use of cells such as thick-film sodium or potassium emission cells, whose range of sensitivity is limited to the blue, violet, and near ultra-violet, but, as the band in use must always cover an appreciable range of wave-length, the effect is never entirely absent, so that the opacity of homogeneous water will appear to decrease with increase of depth.

The second disturbing effect, varying obliquity, is probably less important. It is evident that true absorption, by reducing the oblique rays more rapidly, reduces the average obliquity, and that at a great depth, in the absence of all scattering, the light would be almost vertical. Thus a perfectly limpid homogeneous liquid would show a reduction in the vertical extinction coefficient with increase of depth, even with monochromatic light. Scattering, however, tends to increase the obliquity, and such few experiments as we have made with a vertical photometer window seem to indicate that the ratio of the horizontal to the vertical light is almost independent of the depth. It is probable that a balance between the effects of absorption and scattering is attained at a moderate depth — say 10 metres — and that at deeper levels in

mogeneous water the average obliquity is fairly nstant. We should, however, expect the obliquity be greater in the more turbid waters, so that the rtical extinction coefficient must give an enced estimate of their turbidity. Clarke found significant variations in the coefficient in the lf of Maine with changes in the surface light unlight altitude 13° to 64°, or dull grey sky) the state of the water surface (sea slight to ugh), thus confirming earlier observations of own in the English Channel.

Another minor effect may be worth mentioning ugh it is unlikely to be of importance. Since e of the light is scattered through more than 90°, photometer with an upward-turned horizontal ndow is not entirely unaffected by light coming m below. This is generally only a few per cent. the downward light, so that the fraction scatd back again into the photometer is negligible. is possible, however, that in shallow or comatively turbid water close to a light-coloured tom the increase in the reading due to this ct might be appreciable. In very shallow water r a light bottom much of the light scattered k by the latter will undergo total reflection at surface, so that the total illumination available photosynthesis may be considerably increased.

For blue or green light in average off-shore er μ is likely to lie between 0.1 and 0.2 hough values as low as 0.031 have been found Clarke for blue light in the Sargasso Sea), to find its value, a depth interval of 10 m. is erally convenient. Thus, if $\mu = 0.15$, $\log p_1 - \log p_2 = 10 \times 0.15/2.3 = 0.65$, so that $p_2 = 4.5$. For more turbid waters, or less etrating parts of the spectrum shorter intervals ld be suitable. With such an illumination ratio error of 10 % in the value of p_1/p_2 would an error of 6.5 % in μ. A similar error ld be caused by an error of 65 cm. in the depth rval. With larger values of μ depth errors me even more important.

When conditions render measurements just w the surface difficult it is best to find μ for surface layers from a measurement of p at a h of 5 or 10 m., and an assumption of the ace loss caused by reflection. If the surface e smooth the reflection loss would be about % for diffuse light, but under open sea conditions the average figure seems to be about 15 %. The loss is much less with high sunlight and smooth water, and may be more with low sun or strong wind, but the assumption of a 15 % loss is not likely to cause an error greater than 5 % in the value of μ for an interval of 10 m.

It is possible that the most serious errors in the value of μ may be caused by the drift of the ship in windy weather into water of different average opacity. Thus, if between two readings at 40 m. and 50 m., respectively, the ship drifts into water for which the average opacity is reduced by 10 %, the greater depth in the clearer water is only equivalent to 45 m. in the original water, so that the light reduction only corresponds to a depth interval of 5 m., and the error in μ is 50 %.

Direct Measurement of the Opacity of the Water.

We see, then, that the comparison of the opacities of sea water at different times, places, and depths, from measurements of the submarine illumination is not likely to yield highly accurate results. Moreover, in any but perfectly smooth water, a considerable depth-interval is essential for reasonable accuracy.

There can be no doubt but that Pettersson's method of measuring the intensity of the light of a constant lamp transmitted by a known thickness of water has much to recommend it, and is especially suitable for exploring the rapid changes of opacity with depth which occur in inshore waters.

If, however, this method is to be used for comparing the opacities of ocean waters in different parts of the world, it is obvious that the specification of the apparatus should be standardised, as otherwise it will be difficult to compare the results obtained by different workers with apparatus differing in some important particulars. I would suggest that, in order to render this standardisation easier, some simplification of the design may be desirable, so that any worker could readily construct a replica of the standard apparatus.

In conclusion I should like to thank the Royal Dublin Society for permission to reproduce figures 1 and 2.

References.

Atkins, W. R. G., and H. H. Poole. Phil. Trans. R. Soc. Lond. B. *222*, p. 129. 1933.

Birge, E. A., and C. Juday. Trans. Wisconsin Acad. *24*, p. 509, 1929.

Campbell, N. and Freeth. J. Sc. Inst. *11*, p. 125. 1934.

4. Clarke, G. L. Biol. Bull. *65*, p. 317. 1933.
5. Davis, R., and K. S. Gibson. Bur. Stand., U. S. A. Misc. Publ. No. 114. 1931.
6. Pettersson, H., and S. Landberg. Med. fr. Göteborgs Högskolas Ocean. Inst. *6*. 1934.
7. Pettersson, H. Med. fr. Göteborgs Högskolas Ocean. Inst. *7*. 1935.

8. Poole, H. H., and W. R. G. Atkins. J. Mar. Biol. Ass. *14*, p. 177. 1926.
9. Poole, H. H., and W. R. G. Atkins. J. Mar. Biol. Ass. *15*, p. 455. 1928.
10. Poole, H. H., and W. R. G. Atkins. J. Mar. Biol. Ass. *16*, p. 297. 1929.
11. Poole, H. H., and W. R. G. Atkins. J. Mar. Biol. Ass. *19*, p. 727. 1934.
12. Poole, H. H., and W. R. G. Atkins. Scient. Proc. R. Dub. Soc. *20*, p. 537. 1933.
13. Poole, H. H., and W. R. G. Atkins. Scient. Proc R. Dub. Soc. *21*, p. 133. 1934.
14. Poole, H. H., and W. R. G. Atkins. Phil. Trans R. Soc., Lond. A. *235*, p. 1. 1935.
15. Shelford, V. E., and F. W. Gail. Publ. Puget Sound Biol. Sta. *3*, p. 141. 1922.
16. Utterback, C. L., and J. W. Boyle. J. Opt Soc. America. *23*, p. 177. 1933.
17. Utterback, C. L., and W. Jörgensen. J. Cons Int. p. l'Expl. de la Mer. *9*, p. 197. 1934.

3.

LIGHT PENETRATION IN THE WESTERN NORTH ATLANTIC AND ITS APPLICATION TO BIOLOGICAL PROBLEMS.

BY

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[1]) Contribution No. 101.

DURING the past five years measurements have been undertaken of the penetration of daylight into the sea in both coastal and ...nic areas of the Western North Atlantic. The ...pose of this investigation was to obtain an ...rate description of the conditions of illu...ation at various depths beneath the surface in ...esentative localities. This information was ...ht on one hand as essential to the study of ... factors controlling the diurnal vertical mi...on of plankton. Furthermore, a far-reaching ...ificance must be attached to a knowledge of ... amount and nature of the radiant energy ...ath the sea's surface in relation to the photo...esis of diatoms — the ultimate producers of ...ea. Finally, the degree to which light pene...s is of interest as determining to what extent ...n is possible for fish below the surface zone ...ey go about their daily business.

Methods.

...ll our observations have been made at sea ...r from the research vessel "Atlantis" — in ...hore localities — or from the power boat ...erias" — in the Woods Hole region. The ...oelectric method of measurement developed by ...le and Atkins has been employed ex...vely until recently when a pair of rectifier ... of the "Photox" type produced by the ...inghouse Electric and Manufacturing Company ...een employed. The arrangement of the photo...ic cells in water-tight cases and the carefully ...ated potentiometer have been completely ...ibed by Gall and Atkins (1931). The ...ox cells are used with a microammeter of ...cale reading of 25 microamperes with suitable ...s for the higher intensities and a diaphragm ...duce the size of the receiving window in ...g daylight. The characteristics and the stan...zation of the Photox photometer have been ...ted by Powell and Clarke (1936).

...he photoelectric photometers have proved very ...actory especially under conditions of steady ...ination. Their high sensitivity makes them particularly valuable for exploring the limits of measurable light in deep water. The Photox photometers are more convenient because of their small size and the simplicity of the equipment which is used with them. These photometers are particularly useful for work in situations where the light varies rapidly and a measurement of the average illumination is desired. With the potentiometer method reliable measurements in the upper strata in rough weather are often impossible, but the needle of the microammeter employed with the Photox photometers is so highly damped that it tends to remain at a reading equal to the average value of the fluctuating illumination. Altho less sensitive than photoelectric cells without filters, the Photox photometers, which are sensitive chiefly to the green, were found to respond to practically as weak light as could be measured by the photoelectric photometer when limited by filters to the green part of the spectrum. Table I summarizes the characteristics of the various photometers employed (See also Clarke, 1933 a; Clarke and Oster, 1934; and Oster and Clarke, 1935).

Comparative Transparency of Different Types of Atlantic Water.

The measurements of light penetration which have been undertaken in areas of the North Atlantic ranging from mid-ocean to Continental Shelf and in-shore waters reveal a profound variation in transparency. The extremes of this variation are illustrated in Fig. 1 in which the transparencies of four types of water to the blue component of daylight are compared. Taking the depth at which the light is reduced to 1 % of its surface value as a convenient method for visualizing differences in transparency, it is seen that in Woods Hole Harbor such a reduction is found at a depth of only 8 m. while in the Sargasso Sea the 1 % value is not encountered until a depth of 149 m. is reached. The water of the deep basin of the Gulf of Maine is intermediate with a depth of 32 m. for a reduction to 1 %. A transparency similar to that

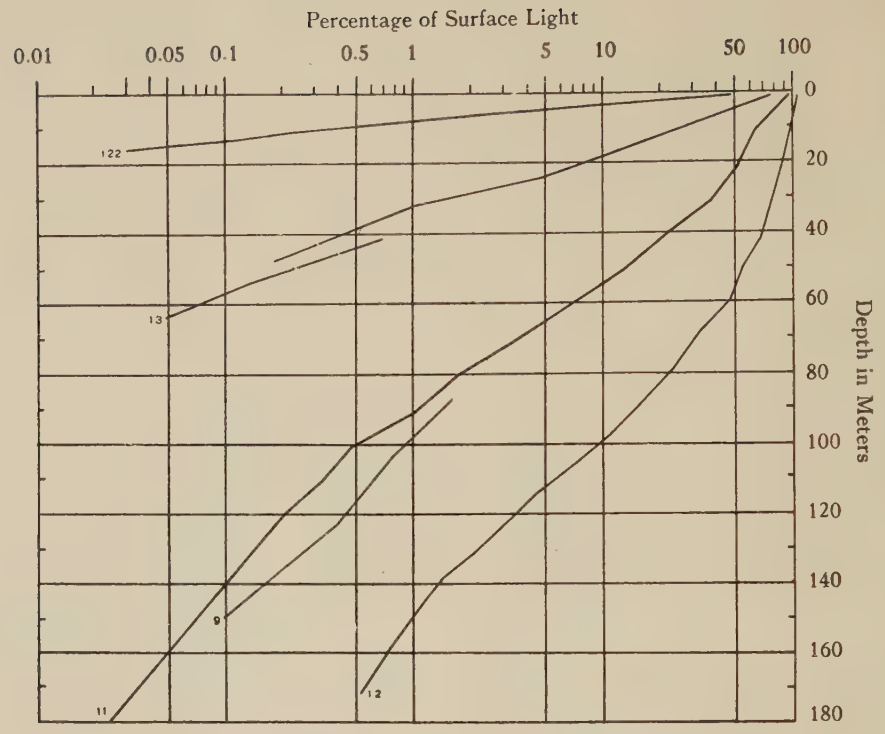

Fig. 1. Comparison of transparencies of four areas in the North Atlantic to the "blue" component of daylight.

Series 9 — near Azore Islands.
„ 11 and 12 — Sargasso Sea.
„ 13 — Gulf of Maine.
„ 122 — Woods Hole Harbor.

Table I.

Characteristics of Photometers Employed.

Maximum Spectral Sensitivity.	Range of Sentitivity.	Type of Cell.	Filters Used.	Irradiation within range of sensitivity necessary to produce current of 1 μa.
		Photoelectric Cells[1])		
"Blue"	3460—5260 A°	Potassium (sensitized)	None	135—315 μw/cm²
"Blue"	3460—5260 A°	Potassium (Gas-filled and sensitized)	None	63
"Violet"	3100—4500	Potassium (unsensitized)	None	181
"Red"	6000—7000	Caesium	Schott-Jena RG—1 and $CuCl_2$ solution	1340
"Green"	4900—6200	Caesium	Schott-Jena BG—18 and GG—11	1885
		Rectifier Cells[1])		
"Green"	4650—6250	Copper-oxide (Photox)	None	7

[1]) The minimum current which can be measured by the potentiometer used with the photo-electric cells is 0.001 to 0.005 μa depending upon the dark current. The minimum current which can be measured using the microammeter employed with the Photox cells is about 1 μa.

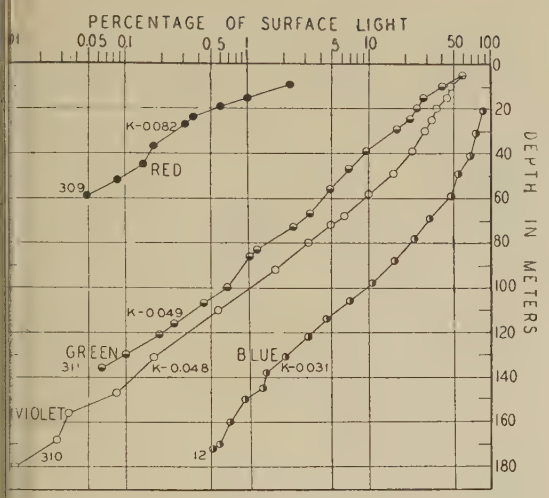

Fig. 2. Penetration of daylight in Sargasso Sea and Gulf Stream.

Series 309 — Station 2243.
„ 310 and 311 — Station 2245.
„ 12 — Station 1041.

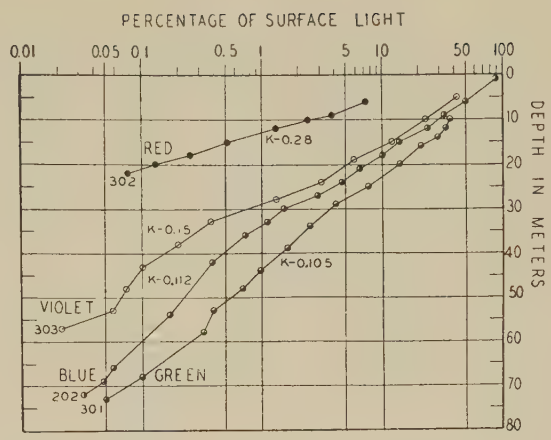

Fig. 3. Penetration of daylight in deep basin of Gulf of Maine.

Series 301, 302, and 303 — Station 2237.
„ 202 — Station 1722.

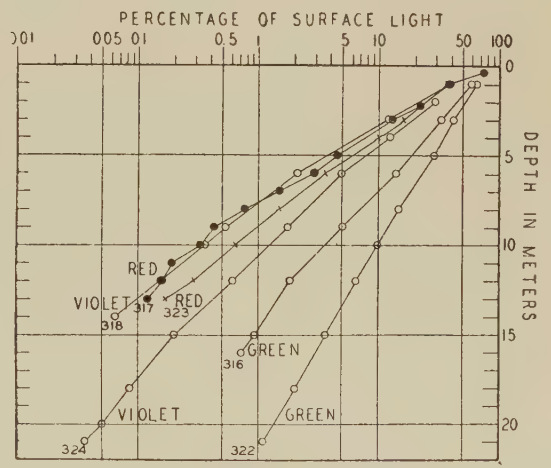

Fig. 4. Penetration af daylight.

Series 322, 323, and 324 — Vineyard Sound.
„ 316, 317, and 318 — Woods Hole Harbor.

he Gulf of Maine typifies mid-Atlantic water atitude 52° N., but from this point south the sparency was found to increase rapidly l a r k e, 1933 a).

Not only do the coastal and oceanic areas in-igated vary profoundly in general clearness also they differ in their relative transparency ifferent parts of the spectrum. A comparison he penetration of the red, green, blue, and et components of daylight into three represen-e types of water, may be made from Figs. 2, nd 4 which show the conditions in the Sargasso and Gulf Stream, in the deep basin of the of Maine, and in Vineyard Sound and Woods Harbor respectively.

The water in the Sargasso Sea and Gulf Stream found to be more transparent than any other on in the world where observations have been e (with the possible exception of the Mediter-an where G r e i n (1913—14) obtained cer-high but doubtful values). In fact, the ness of the water is so great in this part of ocean that the values of the transmissive nent, k, approach — and in one case surpass (C l a r k e, 1933 a) — those for distilled water etermined by S a w y e r (1934). In this type water blue light penetrates best, green and et are about equal, and the red component is rapidly absorbed.

A measurement in the Gulf Stream south of Grand Banks (Station 2484) was kindly carried for me by Mr. A l f r e d W o o d c o c k on ember 15, 1935. using the Photox photometers en sensitive). The value of the transmissive nent was $k = 0.082$ from 2 m. to 10 m. From n. to 95 m. the transparency was found to be extremely uniform with a value of $k = 0.057$. The water at this station was therefore only slightly less transparent to green light than was the case at the stations north of Bermuda (Table II) which are about 1000 miles distant.

The transparency of the deep basin of the Gulf of Maine appears to be characteristic of coastal water well out on the continental shelf. The values obtained in this area are generally similar to those reported by A t k i n s and P o o l e (1933) for the English Channel and by U t t e r b a c k and J o r g e n s e n (1934) for a point 28 miles off Vancouver Island. In the Gulf of Maine the blue and green components penetrate

Table II.

Comparison of Average Values of the Transmissive Exponent, k,[1]) in Oceanic and Coastal Areas of the Western North Atlantic (Arranged in order of decreasing transparency).

Locality	Station	Position	"Red"	"Green"	"Blue"	"Violet"
Sargasso Sea, E of Bermuda ...	1041	36°55′ N 52°41′ W	—	—	0.031	—
Gulf Stream, N of Bermuda	2245	37°35′ N 68°44′ W	0.13	0.049	—	0.048
Sargasso Sea, N of Bermuda ..	2243	35°52′ N 65°30′ W	0.082	0.050	—	0.053
Gulf Stream, S of Grand Banks.	2484	39°56′ N 48°40′ W	—	0.059	—	—
Continental Slope, S of Nantucket Shoals	2246	39°27′ N 69°43′ W	0.23	0.074	—	0.098
Deep basin of Gulf of Maine ..	2237 (+ 1722)	42°08′ N 69°04′ W	0.28	0.11	0.112	0.15
Continental Shelf, S of Cape Cod	2474	40°48′ N 71°00′ W	—	0.11	—	—
Georges Bank	2238 (+ 1723)	40°48′ N 68°40′ W	0.35	0.13	0.14	0.17
Off Gay Head	—	41°20′ N 70°57′ W	0.37	0.16	0.27	0.25
Vineyard Sound	—	41°30′ N 70°36′ W	0.46	0.20	0.36	0.36
Provincetown Harbor	—	42°03′ N 70°11′ W	—	0.23	—	—
Buzzards Bay	—	41°33′ N 70°42′25″ W	0.50	0.25	0.51	0.40
Woods Hole Harbor	—	41°31′ N 70°40′ W	0.56	0.30	0.49	0.55

[1]) In the equation $I/I_0 = e^{-kL}$ where L is the thickness of the water layer (in meters) in which the intensity is reduced from I_0 to I.

about equally well. For violet light the transmission is slightly lower but for red it is only half as great as for the blue and green.

The low transparency found in Wood Hole Harbor and Vineyard Sound is characteristic of inshore waters generally, the conditions here being similar to the San Juan Archipelago (Utterback and Boyle, 1933) and Baltic Sea waters (Pettersson and Landberg, 1934). In these localities the green component of daylight penetrates the most effectively; the red, blue, and violet components are absorbed much more rapidly and do not differ greatly among themselves. Altho it has long been known that many lakes and ponds are relatively opaque, the magnitude and universality of this fact in comparison with ocean water was brought home to us only when we discovered that the transmissive exponent for green light for the clearest lake water ever tested (Crystal Lake, Wisconsin, cf. Birge and Juday, 1931—32) is almost exactly the same as our value for Vineyard Sound.

All the localities where measurements have been made in the Western North Atlantic are arranged in order of transparency in Table II and the average values of the transmissive exponents for the four components of daylight are compared. To generalize from this table we see that the Sargasso Sea is 2 to 4 times more transparent than the Gulf of Maine and the latter is 3 to 4 times more transparent than Woods Hole Harbor. The exact amount of the difference depends upon which part of the spectrum is compared; for example, the transparency of the Sargasso Sea is greater than that of Woods Hole Harbour by the following factors for different parts of the spectrum: 6X for green, 7X for red, 11X for violet, and 16X for blue. In other words the great increase in transparency experienced in going from inshore waters to oceanic regions consists chiefly in a very extensive improvement in the penetration of the shorter wave-lengths.

Reflection and Absorption at the Surface.

In the foregoing measurements and in those of other investigators a "loss" of considerable magnitude has often been encountered at the surface. Attempts to measure the light present just beneath the surface of the water for comparison with that just above the surface have usually been unsuccessful because the action of the waves and the motion of the ship have made it impossible to keep the submarine photometer in the desired position long enough to make a measurement. Furthermore, the light for several meters below the surface fluctuates so rapidly that it is very difficult to obtain a reliable reading at these levels particularly when using the potentiometer method. The result is that the depth of the first point of observation has often not been less than 5 meters in off-shore localities and occasionally no satisfactory measurement could be obtained short of 10 m. When the curves representing the penetration of light from the first point downwards are extended upwards to zero depth, it is commonly found that they strike

bscissa at points indicating a reduction in the at the very surface of from a few per cent. to r 60 %. This discrepancy has been termed the face loss".

During the past summer measurements were ed out (Powell and Clarke, 1936) to rmine whether large surface losses actually do or whether they could be accounted for by instrumental or observational error. In ad- it was hoped that it would be possible to nguish between the loss due to reflection at urface from the apparent loss which would be uced by a stratum of less transparent water h might have existed undetected just beneath urface.

he incident light I at the surface of the sea may ivided into three components: A, that which trates the surface and is entirely absorbed e sea; R, that which is reflected either at the th surface of the water or by white foam and les on the surface; and U, that which pene- s the surface but is scattered back by par- and bubbles in the water below and finally ins to the air. Therefore,

$$I = A + R + U.$$

he magnitudes of the three components A, R, U may be determined by placing a photometer rious positions relative to the sea surface and paring the values obtained with I, the intensity d with the receiving surface of the photometer d upwards and horizontal. If the instrument spended over the sea in an inverted position, easures the quantity $R + U$ which is the total coming upward from the sea's surface. If the meter is lowered in an inverted position to a just beneath the surface, U can be measured .

he total light passing downwards through the ce is $A + U$, but this quantity cannot be ured directly with precision as already ex- ed. However, since I, U, and $R + U$ can all ccurately measured, the values of A and R can be calculated. The quantity $R + U$ is of ular interest as being that fraction of the falling on the ocean which does not contri- to its supply of energy. The remaining light, h is the quantity A, is absorbed by molecules ter, by bubbles, by suspended particles, and ganisms. This component is the entire source eat for the ocean (if infrared radiation is ded) and is responsible for all the photo- ical reactions of marine organisms.

he light passing upward from the surface of ea was measured by suspending the "deck" meters in an inverted position at the top of a ng tower constructed of pipe and mounted on ls. The heavy "sea" photometers were ted on gimbals and used to measure the illu- ion on deck. Since the light from the sur- of the water fluctuates rapidly the potentio- meter method which gives an instantaneous measurement could not be used satisfactorily. In its stead a circuit involving a thyratron tube and relay was employed. The relay was so arranged that each time it became excited it moved the escapement of a watch thus registering the number of discharges and allowing the intensity of the light to be integrated over any desired period of time.

When the Photox rectifier cells had been procured further reflection measurements were made by mounting one of them in a light case and attaching it to the end of a long bamboo pole. In this way the photometer was held about 4½ m. out over the side of the boat and measurements were made with the receiving window turned alternately upward and then downward.

The obervations on the total upward light, or $R + U$, made with the red, green, and violet sensitive photometers showed that only a slight difference exists in the values for these components of daylight. $R + U$ for red light was almost always somewhat lower than for violet and green was intermediate as would be expected from their relative indices of refraction.

$R + U$ reaches a minimum (about 4 % for violet and 3 % for red) on clear days when the sun is nearest the zenith; on cloudy days the value may reach 6 or 7 %. After the sun has fallen below about 44° from the horizon the value of $R + U$ begins to rise. Below 30° on a clear day $R + U$ becomes steadily higher, and is higher then than under any other conditions. From 12° on the inaccuracy introduced by the unavoidable tilting of the photometers invalidates the measurements but there is every indication that $R + U$ becomes very high as predicted by theory. For solar altitudes of 12° to 30° $R + U$ ranged between 6 and 20 % in clear weather. White caps were found to increase $R + U$ only slightly, apparently because the foam produced covers a relatively small proportion of the total surface. This is in agreement with a value of 12 % obtained over the foamy part of the boat's wake. Altho the magnitude of the upward light has been found to remain an inconsiderable fraction of the incident light under all conditions, it must be remembered that its percentage may be two or more times greater on one occasion than on another and its absolute value varies with the strength of daylight.

Since these results point to a much lower value for the loss of light at the surface than was indicated by previous measurements of submarine illumination, an attempt was next made to measure with more care and precision than before the intensity of the light just below the surface.

Under conditions of absolute calm, clear sky, and glassy smooth water in Buzzards Bay it was possible to make measurements up to within 10 cm. of the surface where 97.5 % of the light was transmitted (Series 401, Fig. 5). The trend of the

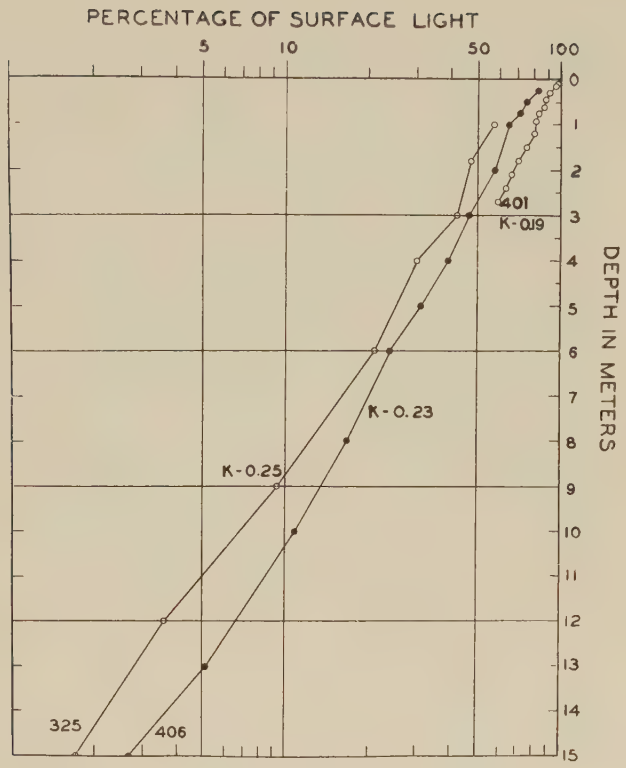

Fig. 5. Penetration of daylight showing "surface loss" under different conditions.

Buzzards Bay: Series 325. Slight sea.
„ 401. Glassy smooth sea.
Provincetown Harbor: Series 406. Slight sea.

curve is straight from this point to a depth of 2.7 meters. When the curve is extrapolated to zero depth a value of about 100 % is reached. A short time later when the sun was about 35° from the horizon $R + U$ was found to be 8.4 %. Since the theoretical reflecting power, R, for light incident at this angle as calculated from Fresnel's law of reflection for a smooth water surface is 5 %, the value of U alone must have amounted to about 3.4 % or almost half of the total upward light.

The situation is entirely different when the surface of the sea is disturbed as is revealed by a comparison with Series 325 made at the same place the year before on a day when small waves existed. If the curve is extrapolated beyond the 1 meter level, a "surface loss" of about 30 % is indicated. Since the value of the transmissive exponent for the upper 6 meters ($k = 0.19$) is identical with that for Series 401, the difference in the position of the two curves cannot be due to a difference in the transparency of the water on the two occasions. Furthermore, we know from our present investigation that $R + U$ could not have been as great as 30 %. It was therefore suspected that the stratum of water less tha 1 meter thick just beneath the surface becan relatively opaque when the surface of the sea w rough and that this condition disappeared in cal weather.

Such a situation was actually detected i measurements made in Provincetown Harb (Series 406) on a clear day with wind force (Beaufort Scale), small waves, and occasion flecks of foam. If the curve is extrapolated t zero depth using only points below 1 meter indicates a surface loss of 15 % or more. B when one extrapolates from points above 0.5 met a loss of only 6 % is found. In this case $R + U$ was 4.6 % and U, measured directly by invertin the sea photometer and lowering it a few cent meters beneath the surface, was 3 %. The abru change of slope in the curve reveals the increase rate of absorption and scattering within the firs meter of water.

In the open sea with waves a meter or more hig and white caps, values for $R + U$ of 5.5 an 4.6 % were obtained at stations on Georges Ban and south of Cape Cod respectively. At the latte station it was possible in addition to make sub marine measurements from a depth of 50 meter up to 0.5 meters (Series 412, Fig. 6). Without thi last point on the curve the surface loss appear to be 14 % while with it the loss is reduce to almost nothing.

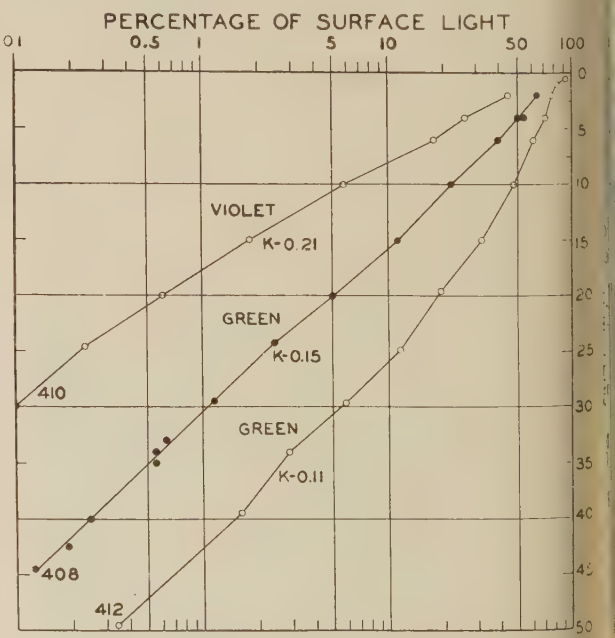

Fig. 6. Penetration of daylight showing presence of "opaque layer" just beneath surface.

Georges Bank: Series 408. Moderate sea.
„ 410. Moderate sea.
South of Cape Cod: Series 412. Moderate sea.

From the foregoing observations we may conclude that the discrepancies which have been termed "surface losses" are not due chiefly to a "loss" at the very surface. They are due, however, to a layer of relatively opaque water which exists just beneath the surface and which has generally escaped notice.

The average value of all our measurements of U for solar altitudes greater than 30° is about 6 % for cloudy days and about 4 % for clear days. Differences in the condition of the sea surface ranging from flat calm to waves with white caps has very little effect on these figures. The value of $R + U$ was not more than a few units greater in the more opaque inshore waters than in the clearer water of the Gulf of Maine. $R + U$ was never more than 9 % except for solar altitudes greater than 30° in clear weather. These conditions would exist during only a small portion of the day for most of the ocean, but the greater reflection losses at lower solar altitudes is undoubtedly of considerable importance in polar seas. For values of $R + U$ of 9 % or less, R and U were found to be about equal in magnitude. Therefore the portion of daylight which never enters the water at all, namely R, is never more than a few per cent. of the incident light and consequently of negligible importance. These results agree very closely with measurements of the reflection from the surface of certain rivers and of Chesapeake Bay made by Kimball and Hand (1930) from an aeroplane of altitudes varying from 10 to 1000 ft.

Under conditions of absolute calm the transparency of the water remains unchanged up to within at least 10 cm. of the surface. The "surface loss" deduced from extrapolation is very small and in agreement with the low magnitude of the reflection. But as the sea's surface becomes more and more disturbed, the "surface loss" discrepancy becomes larger and larger. Its magnitude is usually about 15 % but has often been reported as much greater. Since we have found that the value of U does not become significantly larger under rough conditions than in calm weather, it follows that the amount of light absorbed in the upper foot or so has greatly increased. Careful investigation of this stratum has proved that this is indeed the case.

The cause of this diminished transparency of the surface layer is undoubtedly the presence of bubbles produced by a disturbance of the water. Chemical substances, particles of sediment, and planktonic organisms are uniformly distributed to a much greater depth than the thickness of the anomalous stratum by the vertical mixing produced by turbulence. In every case where a "surface loss" has been recorded either white water or a tide rip has existed. In calm weather the phenomenon disappears.

Rate at which Submarine Light becomes Diffuse.

The upward component of light beneath the surface was measured with an inverted photometer at each meter to a depth of 14 m. in Provincetown Harbor where the depth is about 16 m. At 0.5 m. the upward component was found to be 4 % of the downward component and this ratio increased gradually to a value of 6 % at 14 meters. In Buzzards Bay (depth 15 m.) the ratio was found to be 4.8 % at 1 m., 5.8 % at 5 m., and 8.9 % at 10 m. In the deep basin of the Gulf of Maine a ratio of 2.5 % was obtained at 0.5 m. and this value remained unchanged to a depth of 20 m.

A few approximate measurements of the horizontal component of the submarine illumination were made by suspending the sea photometer by one end so that the receiving surface was vertical. The photometer was caused to rotate slowly around a vertical axis in order that the window might face successively in all directions relative to the direction of the sun which was unobscured. A maximum and minimum intensity was thus recorded for each depth. In Provincetown Harbor the ratio of the maximum value for horizontal illumination at 1.5 m. to the vertical downward illumination at the same depth was 16 % and the ratio of the minimum horizontal illumination to the vertical illumination was 3.4 %. At 10 m. these ratios had increased to 17 % and 7 %, respectively. In the deep basin of the Gulf of Maine the ratios were 6 % and 3 % at 2 m., and 20 and 3 % at 15 m. Poole and Atkins (1929) reported an average value of 50 % for the horizontal light down to 25 m. in the English Channel. It is seen, therefore, that the illumination becomes more and more diffuse with increasing depth, but the directional character of the light is lost only slowly. One recalls that Helland-Hansen (1931) found that the vertical light was measurably greater than the horizontal at 500 m. in the Sargasso Sea.

Diurnal Vertical Migration of Zooplankton.

Many of our measurements of light penetration have been made in connection with the study of the diurnal migration of copepods (Clarke, 1933b, 1934a and b). From careful records of illumination on deck throughout the day and several measurements of the transparency at the station where plankton hauls were being made, it was possible to construct diagrams which showed the changes both in the vertical distribution of the animals and in the intensity of light at the different depths. From an analysis of these it was hoped that the factors controlling the migration might be unraveled.

If there is one generality which can safely be made about the migration of plankton, it is that the phenomenon is an extremely variable one. Not only do different species behave differently, but the reaction of the same species may be quite contrary in one locality to what it is in another, or in the same locality at different times, as Russell (1934) has shown so clearly. If this were not enough, we find that the sexes and the various age groups of the same species in the same body of water often exhibit the most diverse behavior ranging from no migration at all to very extensive and rapid vertical movements (cf. Nicholls, 1933).

For those cases in which a clear cut diurnal migration is found the change in intensity of daylight during each 24 hour period is undoubtedly the most important single cause. In our investigations in the Gulf of Maine the migration of copepods was found to be much more closely correlated with the changes in submarine irradiation than with the changes in the hydrographic conditions or in the phytoplankton. In addition, light is of further significance because it is one of the two physical factors of the environment to which a copepod can respond *directionally*, as I have pointed out elsewhere (Clarke, 1934c). Light, gravity, and possibly stimuli from other organisms appear to be the only forces which can bring about orientation and thus make a consistent movement possible. At depths where the illumination has become so diffuse that the direction of propagation is no longer perceptible to the copepod, phototropic responses cannot take place. The intensity of the light present may, however, affect the sign of geotropism.

Altho light is generally conceded to play a major role in diurnal migration, the manner in which it exerts its effect is by no means clear. It may be that plankton animals are positively phototropic to weak light and negative to strong light. On the other hand it has been suggested that such influences as feeding or change of temperature may control the sign of the phototropic movement rather than the intensity of the illumination. But if phototropism alone is acting it is difficult to understand why the animals continue to move toward the surface after dark, as is often observed to be the case, or why they sometimes leave the surface before dawn. In these cases it seems to me more reasonable to suppose that light acts thru a modification of, or interference with, a persistent geotropism. According to this idea the negative reaction to light is thought to overpower the negative geotropism during the morning and noon hours but is less effective in the afternoon when light-adaptation has taken place. In cases where withdrawal from the surface occurs before dawn we would have to assume that some other factor acting in the upper strata reversed the geotropism after a certain number of hours.

For animals which remain continually in the deeper strata we may postulate a positive geotropism, and for those that swarm near the surface even during the middle of bright days, we must assume a negative geotropism which is stronger than any tendency to move away from the light. But the validity of these assumptions must be tested by suitable experiments in the laboratory and more precise observations at sea before any of these explanations can be excepted. The picture which seems to emerge from all this, however, is one of a plankton whose physiological adjustments are in a very delicate balance. Evidently very slight changes in the environment or undetectable differences in the internal physiological states of different ages or sexes or broods are sufficient to completely reverse the sign of the reactions.

The Metabolism of Diatoms.

Since the photosynthesis of diatoms is of such fundamental importance in the sea, it is unfortunate that we do not have more information on the needs and limitations of this process in relation to the distribution of submarine illumination. On the western side of the Atlantic three experiments have been carried out in which the metabolism of diatoms was measured in bottles suspended at different depths in the sea, some of which were covered with black cloth and others of which were left exposed to the radiant energy existing in the surrounding water.

For the experiments in Woods Hole Harbor and in the Gulf of Maine (Clarke and Oster, 1934) phytoplankton from hauls made near by was suitably diluted and placed in the glass-stoppered oxygen bottles. In the Woods Hole Harbor experiment, which was undertaken in collaboration with Professor H. H. Gran, the plankton was exposed for four hours during the middle of the day. At the end of that time it was found that the oxygen consumed in respiration was just balanced by the oxygen evolved in photosynthesis at a depth of about 7 meters — the "compensation point". The fact that at 18 meters the loss in oxygen in the exposed bottles was not as great as in the covered bottles shows that a measurable amount of photosynthesis took place in the extremely weak light which penetrates to that depth, altho the photosynthesis was obviously much less than the respiration.

In the Gulf of Maine experiment, which was carried out by Professor A. C. Redfield, the exposure period extended from five o'clock in the morning to 2 o'clock in the afternoon. During this time the "compensation point" occurred at 24 to 30 meters, but some photosynthesis was detected down to 40 meters. The water in the Gulf of Maine is roughly three times as transparent as in Woods Hole Harbor and the "compensation point" lies about three times as deep.

t is of interest to compare with these results xperiment carried out for me by Mr. S. S. l i s in the Sargasso Sea where the radiant gy is so much more intense. Since the diatoms ing naturally in this area could not readily rocured in sufficient concentration to produce urable changes in the oxygen bottles, a per- t culture of *Nitzschia closterium* was used for experiment. However, the photosynthesis of northern diatom under the unnatural con- ns of high temperature and intense illumi- n may have been very different from that h would have resulted had it been possible to native species. This possibility must be borne nd when interpreting the results (Table III). ince this is the only experiment of its kind in cal oceanic water to my knowledge, the data valuable as a first approximation.

Table III.

Metabolism of Diatoms in Sargasso Sea.

tent culture of *Nitzschia closterium* used.
ure Period: 1050—1650, Aug. 24, 1934.
clear. Sea: smooth.
n present before exposure: 7.62
7.57
7.51
av. 7.57 cc./liter.

Temp. °C.	Condition of bottles.	Oxygen after exposure cc./l.	Change in oxygen cc./l.	Difference in exposed and covered bottles cc./l.
24.0	Covered	7.78	+ 0.21	
	Exposed	11.22	+ 3.65	+ 3.44
	Exposed	11.15	+ 3.58	+ 3.37
21.5	Covered	7.51	— 0.06	
	Exposed	13.45	+ 5.88	+ 5.94
	Exposed	13.48	+ 5.91	+ 5.97
20.2	Covered	7.70	+ 0.13	
	Exposed	14. 11	+ 6.54	+ 6.41
	Exposed	14.90	+ 7.33	+ 7.20
19.5	Covered	7.68	+ 0.11	
	Exposed	11.71	+ 4.14	+ 4.03
	Exposed	11.41	+ 3.84	+ 3.73
19.1	Covered	7.60	+ 0.03	
	Exposed	9.87	+ 2.30	+ 2.27
	Exposed	9.75	+ 2.18	+ 2.15
18.9	Covered	8.01	+ 0.44	
	Exposed	8.51	+ 0.94	+ 0.50
	Exposed	8.25	+ 0.68	+ 0.24

results in this experiment are unfortunately regular as was the case in the Gulf of Maine nd considerable difference is found between in the same categories. Furthermore, all the bottles except one showed a slight increase gen instead of a decrease as they should if re to be used as a measure of respiration alone. Possibly the light which reached them during manipulation at the beginning and end of the experiment was sufficient to account for this. However, if one assumes that this error was the same for all the bottles at each level, we may find the amount of photosynthesis which occurred at the designated depths by subtracting the oxygen produced in the covered bottle from that produced in the exposed bottles, altho the location of the "compensation point" is unfortunately impossible.

The differences in the amount of oxygen produced in the exposed bottles at the different levels is so very great that in spite of these irregularities we may draw two rather significant conclusions. In the first place it is seen that the greatest amount of photosynthesis is found at the 80 meter level. Evidently the more intense illumination (or possibly the higher temperature) of the upper strata exerted an inhibitory effect. This is in sharp contrast to the other experiments in which the largest production of oxygen took place just under the surface. The other conclusion of interest is that a considerable amount of photosynthesis went on even at a depth of 140 meters — 100 meters deeper than the lowest level of detectable oxygen production in the Gulf of Maine series.

These three experiments give an impression of the depth to which photosynthesis may extend in three different areas of the sea. They do not, however, show the thickness of the stratum in which constructive production goes on during the whole 24 hours of the day or longer periods (cf. M a r s h a l l and O r r, 1928; and P e t t e r s s o n, H ö g l u n d, and L a n d b e r g, 1934). This is obviously the significant information from the point of view of the fertility of the sea and it is to be hoped that more extensive experiments will be undertaken in the near future on this problem — particularly in the great oceans.

The Depth at which Fish can see.

At what maximum depth fish can see in the ocean and in lakes has remained a matter for speculation up to the present time, first because little was known regarding the strength of the illumination at various depths and second because no adequate tests of the sensitivity of the fish eye had been made. However, the recent work by G r u n d f e s t (1932) on the sensibility of the sun-fish, *Lepomis*, has provided us with reliable values for one species of fish. With this information and our present knowledge of the penetration of light it is possible to make an approximate calculation of the greatest depth in several different types of water at which the sunfish could just discern an object of a certain size at a given distance. Whether the photosensitivity of other fish is similar to that of *Lepomis* can be

decided, of course, only by the performance of suitable experiments. The vision of fish with "telescopic" eyes and of other highly specialized species is undoubtedly on an entirely different scale[1]).

Grundfest tested the response of the sun-fish to the movement of a screen illuminated by bands of light in different parts of the spectrum and found that radiation between wave-lengths 530 and 550 mμ was much the most effective. It is this general part of the spectrum of daylight which penetrates most effectively into most lakes and into coastal ocean water — the part of the sea in which fish occur in the greatest abundance. The minimum illumination, in the most effective region of the spectrum, under which the fish would respond was 1×10^{-6} millilamberts. Since the bars of the screen used in the experiment were 2 mm. broad and at a distance of 1 cm. from the fish's eye (thus subtending an angle of about 11°), we may assume that the fish could just see under this minimum illumination an object 2 mm. in diameter at a distance of 1 cm., or a 2 cm. object at 10 cm., or a 20 cm. object at 1 meter, and so on.

The irradiation from 490 to 620 mμ at the surface of the sea off the coast of Massachusetts during the middle of a bright day in summer reaches an intensity of about 20,000 microwatts/cm². Now the minimum brightness for the vision of the sun-fish of 1×10^{-6} millilamberts is equivalent to an irradiation of 1.5×10^{-6} μw/cm². Since an intensity of 20,000 μw/cm² is approximately 10^{10} times this, it is apparent that the fish can see under an illumination of 10^{-10} times the maximum value of daylight — or a reduction of ten logarithmic units. This is approximately the same as for man. The instruments which have been found practicable for light penetration investigations have not been sufficiently sensitive to follow the reduction of light in the water for more than three, or at most four, logarithmic units. However, if we assume that the transparency of the water below the maximum depth reached by the photometer is the same as that in the surface strata, the data may be extrapolated. This assumption is justified, to some extent at least, by the fact that in many cases (and in all the cases considered here) there is no radical change in transparency within the depths actually measured. Accordingly, the approximate depth at which the minimum intensity for vision exists (during the hours of bright daylight at the surface) for each type of water

[1]) A correlation undoubtedly exists between the degree of enlargement or of degeneration of the eyes of deep-sea fish and the depth (and consequently the illumination) at which they live. The issue is confused, however, by important differences which apparently depend upon whether the fish is bottom-living or pelagic and whether or not it possesses light organs. This problem has not yet been satisfactorily elucidated. *Cf.* Murray and Hjort (1912, p. 680).

Table IV.

Maximum depth for vision of fish similar to *Lepo* in various types of water.

Types of water.	Thickness of stratum causing reduction of 1 log unit.	Depth of minimum illumination for vision of fish similar to *Lepomis* (10 × column 1)	
	m.	m.	
Deep Basin of Gulf of Maine	23	230	
Georges Bank	18	180	
Woods Hole Harbor	7.5	75	
Off Gay Head	13	130	
Sargasso Sea	43	430	4
Crystal Lake, Wisconsin	11	110	
Adelaide Lake, Wisconsin	2.8	28	
Trout Lake, Wisconsin	6	60	
Gunflint Lake, Minnesota	7	70	

investigated has been calculated by finding average number of meters of water causing a duction in intensity of one logarithmic unit a multiplying this value by ten.

In so far as it is reasonable to assume that vision of our common marine fishes is similar that of *Lepomis*, which inhabits fresh-water po and lakes, the figures in the upper part of Table give the extreme depths at which vision would possible in different types of water. According these approximations fish would be able to objects on the bottom in coastal waters. In case of localities where the "depth of minim illumination" is much greater than the depth to bottom, such as Georges Bank, it appears t vision would be possible for fish during most the day because the intensity of daylight is wit one logarithmic unit of its maximum for seve hours before and after noon. Altho taste, sm and touch are undoubtedly used in certain ca for the location of food, most fishes appare depend chiefly upon sight. The general conclusi that vision is possible for fish on the bottom coastal waters is supported by the following o servation made by Mr. R. A. Nesbit of United States Bureau of Fisheries. Mr. Nes found that white hake which he took in a botto trawl at a depth of 132—154 m. off Bodie Isla North Carolina, were gorged with butterfish a other small active fish which presumably the ha could not have caught unless they had been ab to see at that depth.

In order to compare these data on fishes wi the ability of divers to see under water, I ma inquiries of Mr. H. V. Greenough who ha been working with conventional diving equipme on a wreck in 29 m. of water in Vineyard Sou about five miles distance from the point off G

H where our light penetration measurements been made. Mr. G r e e n o u g h told me that hat depth tools could be clearly seen at arm's th during several hours in the middle of bright in July. On one occasion sufficient light ed to permit work on the wreck to continue 7 o'clock in the evening.

he value arrived at for the Sargasso Sea of meters is of interest in comparison with b e's observation from the Bathysphere that plete darkness for the human eye was reached depth of between 520 and 580 m. Dr. B e e b e informed me (private communication) that ut artificial illumination he was able to see n-luminous fish four inches long *(Cubiceps)* depth of 210 m., a shark at 240 m., and a -fish *(Aurelia)* at 350 m. altho entangled nescent organisms may have aided vision in ast case. If we assume that a deep sea fish see as well in blue light as *Lepomis* can in light, then the maximum depth for vision in argasso Sea would be about 750 meters since verage of 75 m. of this type of water are red for a reduction of one logarithmic unit blue region of the spectrum.

The depths for the limit of vision for the sunfish have been similarly calculated for three of the large number of lakes in northern Wisconsin whose transparencies have been carefully studied by B i r g e and J u d a y (1931, 1932) and for one lake in Minnesota investigated by E r i k s o n (1935), altho the different methods used in the measurement of light penetration make comparisons difficult. The values arrived at for these four lakes are set forth in the lower part of Table IV. Crystal Lake is the clearest of all those investigated and Adelaide Lake is one of the most turbid with the exception of those which are deeply stained. Trout Lake is the deepest of the Wisconsin lakes studied. In all of these and even in Gunflint Lake which is still deeper, the calculations indicate that, just as in coastal waters, vision would be possible for fish similar to *Lepomis* all the way to the bottom.

Acknowledgement.

I wish to acknowledge the valuable collaboration of Dr. R. H. O s t e r and Dr. W. M. P o w e l l in this investigation.

Summary.

Measurements of the penetration of four onents of daylight have been carried out in coastal and oceanic areas of the western North tic using photoelectric cells with a marine tiometer and, more recently, rectifier cells of Photox" type with a suitably damped micro-lter.

The water in the Sargasso Sea and Gulf n was found to be more transparent than in ther region of the world. The transparency e Gulf of Maine is 2 to 4 times lower than nd is characteristic of coastal water on the ental shelf. The water in Woods Hole Harbor 4 times less transparent than in the Gulf of and is representative of inshore waters ge-y and of lakes. The transparency of the sso Sea is greater than that of Woods Hole r by the following factors: 6 × for green 7 × for red, 11 × for violet, and 16 × ue.

The "surface loss" was investigated by ding a photometer in an inverted position he surface of the water and measuring the ight passing upward $(R + U)$. In Buzzards $R + U$ reaches a minimum of 3 to 4 % on lays when the sun is nearest the zenith. The tage is increased by one or two units when exist and by a few units more when the sky is cloudy, and is decreased by a few units in clearer off-shore waters. The greater part of the "surface loss" is due to a stratum of relatively opaque water which extends in rough weather to a depth of about 1 meter.

4. Measurements of the upward and horizontal components of the light beneath the surface showed that illumination becomes more and more diffuse with increasing depth, but the directional character of the light is lost only slowly.

5. Light is the most important factor controlling the diurnal migration of plankton and it is one of the two physical factors to which a copepod can respond directionally. However, it has been found that the reactions of the plankton to light are easily altered by slight changes in the environment or in the internal physiological state.

6. Experiments on the metabolism of diatoms in relation to light penetration were carried out in Woods Hole Harbor, in the Gulf of Maine, and in the Sargasso Sea. A measurable amount of photosynthesis was found to occur down to depths of 18 m., 40 m., and 140 m. in the three localities respectively. The "compensation point" for periods of a few hours occurred at 7 m. in Woods Hole Harbor and at 24 to 30 m. in the Gulf of Maine. An inhibiting effect was observed above 80 m. in the Sargasso Sea.

7. The minimum illumination for vision for the sun-fish, *Lepomis*, is approximately 10^{-10} times the maximum value of daylight. The depth at which daylight would suffer a corresponding reduction in different types of water has been calculated. The results indicate that for fish of simi visual sensitivity vision would be possible at bottom in coastal regions and in lakes and a depth of at least 430 m. in the Sargasso Sea.

Citations.

Atkins, W. R. G. and Poole, H. H. 1933. The photo-electric measurement of the penetration of light of various wave-lengths into the sea and the physiological bearing of the results. Phil. Trans. Roy. Soc. *B222*, 129.

Birge, E. A. and Juday, C. 1931, 1932. Solar radiation and inland lakes, Trans. Wis. Acad. Sci. Arts and Let. Madison, *26*, 383; *27*, 523.

Clarke, G. L. 1933 a. Observations on the penetration of daylight into mid-Atlantic and coastal waters. Biol. Bull. *65*, 317.

Clarke, G. L. 1933 b. Diurnal migration of plankton in the Gulf of Maine and its correlation with changes in submarine irradiation. Biol. Bull. *65*, 3, 402.

Clarke, G. L. 1934 a. Further observations on the diurnal migration of copepods in the Gulf of Maine. Biol. Bull. *67*, 432.

Clarke, G. L. 1934 b. The diurnal migration of copepods in St. Georges Harbor, Bermuda. Biol. Bull. *67*, 456.

Clarke, G. L. 1934 c. Factors affecting the vertical distribution of copepods. Ecological Monographs *4*, 530.

Clarke, G. L. and Oster, R. H. 1934. The penetration of the blue and red components of daylight into Atlantic coastal waters and its relation to phytoplankton metabolism. Biol. Bull. *67*, 59.

Erikson, H. A. 1933. Light intensity at different depths in lake water. J. Opt. Soc. Am., *23*, 170.

Gall, D. C. and Atkins, W. R. G. 1931. Apparatus for the photo-electric measurement of submarine illumination assembled for the U. S. A. research ship "Atlantis". J. Mar. Biol. Ass. *17*, 1017.

Grein, Klaus von. 1914. Untersuchungen über die Absorption des Lichts im Seewasser. Monaco Inst. Oceanog. Ann. *5*, 23; *6*, 21.

Grundfest, H. 1932 a. The sensibility of the sun-fish, Lepomis, to monochromatic radiation of low intensities. J. Gen. Physiol. *15*, 307.

Grundfest, H. 1932 b. The spectral sensibility of the sunfish as evidence for a double visual system. J. Gen. Physiol. *15*, 507.

Helland-Hansen, B. 1931. Physical oceanography and meteorology Rept. Michael Sars N. Atlant. Deep-Sea Exp. 1910, *1*, 43, Bergen.

Kimball, H. H. and Hand, I. F. 1930. Reflectivity different kinds of surfaces. Monthly Weather Revi U. S. Weather Bureau, *58*, 280.

Marshall, S. M. and Orr, A. P. 1928. The photos thesis of diatom cultures in the sea. J. Marine B Ass. *15*, 321.

Murray, J. and Hjort, J. 1912. The Depths of Ocean. MacMillan and Co. 819 pp.

Nicholls, A. G. 1933. On the biology of *C. finm chicus* III. Vertical distribution and diurnal migrati in the Clyde Sea-area. J. Marine Biol. Ass. *19*, 1,

Oster, R. H. and Clarke, G. L. 1935. The penetrati of the red, green, and violet components of daylight in Atlantic waters. J. Opt. Soc. Am. *25*, 84.

Pettersson, H., Höglund, H. and Landberg, 1934. Submarine daylight and the photosynthesis phytoplankton. Göteborgs kungl. vetenskaps- och vitte hets-samhälles handlingar. Femte foljden *B4*, 5, 3.

Pettersson, H. and Landberg, S. 1934. Submari daylight. Göteborgs kungl. vetenskaps- och vitterhe samhälles handlingar, Femte foljden *B3*, 7, 4.

Poole, H. H. and Atkins, W. R. G. 1929. Phot electric measurements of submarine illuminatio throughout the year. Journ. Marine Biol. Ass., n. s., 297.

Powell, W. M. and Clarke, G. L. 1936. The re flection and absorption of daylight at the surface the ocean. J. Opt. Soc. Am. *26*, 111.

Russell, F. S. 1934. The vertical distribution of mari macroplankton. XII. Some observations on the vertic distribution of *Calanus finmarchicus* in relation to ligh intensity. J. Marine Biol. Ass. *19*, 569.

Sawyer, W. R. 1934. The spectral absorption of ligh by pure water and Bay of Fundy water. Contr. Can Biol. and Fisheries n. s. 7, 8, 75.

Utterback, C. L. and Boyle, T. W. 1933. Ligh penetration in the waters of San Juan Archipela J. Opt. Soc. Am. *23*, 1.

Utterback, C. L. and Jorgensen, W. 1934. A sorption of Daylight in the North Pacific Ocean. Journ Conseil Int. pour l'Exp. de la Mer *9*, 197.

4.

SPECTRAL BANDS OF SUBMARINE SOLAR RADIATION IN THE NORTH PACIFIC AND ADJACENT INSHORE WATERS.

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Introduction.

ECOGNITION of the great importance of the magnitude and distribution of solar radiation beneath the surface of the ocean as a amental factor in maintaining marine life dates several years. It was natural to attempt to n quantitative information on the subject, and experimenters made use of visual and photohic observations. While their results were of value and aided materially in establishing a dation for further work, they did not yield titative data.

n the last few years W. R. G. Atkins and . Poole, using a photoelectric cell connected potentiometer circuit, have made many urements of the transparency of ocean waters. rge L. Clarke and co-workers at Woods , Massachusetts, have made many determinaof the transparency of ocean waters in the Atlantic and on the east coast of the United employing apparatus similar to that of ins and Poole. Recently Hans Pet- son has made use of photoconductivity cells aking measurements of the transparency and cattering of subsurface solar radiation. Other ers have used different types of cells and nt measuring circuits following the same al procedure of W. R. G. Atkins and . Poole.

n planning for the work on the Pacific Coast, s decided to use a photoconductivity cell in ul marine photometer. There are several dif- t photoconductivity cells of similar charac- ics available. One cell of this type is the n Photronic and while much of our earlier was done with a Photronic, other types seem ssess certain advantages. The Photronic cell nces a current of 130 microamperes for an lination of approximately 100 foot candles, lumens), if the resistance of the external t does not exceed 400 ohms. The current out- s fairly linear with illumination under this tion but departs from linearity with increasing external resistance. The spectral response approximates the visibility curve of the human eye with the maximum response at 5800 A.

The Lange cell is the equivalent of the Photronic in its relative spectral sensitivity, with possibly a slightly lower response in the ultra violet. It excells the Photronic in current output, giving about 400 microamperes per lumen. It has a linear output when used in circuits of low external resistance.

The Electrocell produces a current which is directly proportional to illumination at low light intensities. The current output is approximately 450 microamperes per lumen. The relative spectral sensitivity shows a maximum response at about 5800 A with a high response over a fairly wide spectral band. The sensitivity of this cell can be increased approximately 30 % by the application of a low unidirectional voltage.

At the time of writing, the General Electric Company announces a new cell of the Selenium type. The spectral sensitivity curve for this cell, with a maximum at 5600 A, compares favourably with that of the Electrocell except that it has a lower relative response on the long wave length side. The relative response is less than 5 % at 7000 A. The cell, in combination with a filter which is to be provided, gives a relative response comparable to the spectral visibility curve of the human eye. The filter, however, reduces the response of the cell in daylight by approximately 43 %. This cell produces a current of 140 microamperes with an illumination of 20 foot candles when the external resistance is 100 ohms. The cell has a relatively high current variation with increasing external resistance for constant illumination.

The photoconductivity cell does not require the use of accelerating potentials and thus does away with the troublesome leakage currents and insulation difficulties which arise on work at sea. The early photoconductivity cells had considerable fatigue effect, although this seems to be less in the later types.

Apparatus.

In order to measure the transparency of the water to various spectral bands of solar radiation, the submarine photometer shown in Fig. 1 was constructed.

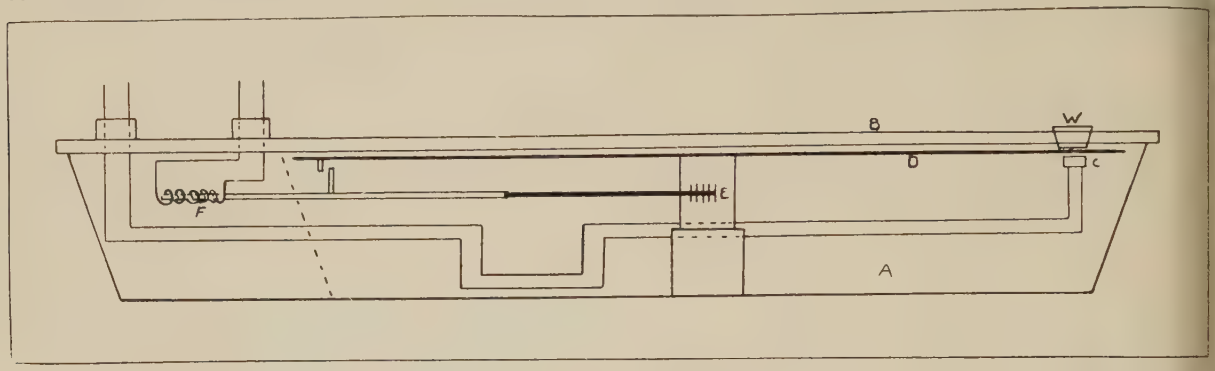


Fig. 1. Schematic Arrangement of the Cell, Color Filters and Filter Shifting Device.

A nickel steel casting, *A*, with a boiler plate cover, *B*, formed the case for lowering the cell and color filters into the sea. A calibrated cell, *C*, was mounted directly beneath a glass window, *W*, and between the window and the cell, with the least possible clearance, was a thin aluminum disk upon which were mounted the color filters. This disk was mounted on a drum which was actuated by means of an electromagnet. The drum was so designed that for each excitation of the electromagnet the disk rotated about a vertical axis through exactly 45 degrees, thus permitting the use of eight color filters on the disk. The cable from the cell and from the electromagnet passed through water tight seals in the boiler plate and terminated on an instrument panel in the ship laboratory. This panel contained two Rawson multimeters, a Leeds and Northrup marine galvanometer, ammeters, voltmeters, rheostats, etc.

One multimeter was connected to a deck photometer for which a duplicate set of color filters were provided. The current from the submerged cell, for relatively high light intensities, was measured with a second multimeter while for lower light intensities it was measured by means of the marine galvanometer. The galvanometer, which was provided with electromagnetic field coils and dynamically balanced, had a very rugged suspension. Its sensitivity was .00118 microamperes. The galvanometer and the multimeters were frequently calibrated.

The cell was calibrated with two sources, sunlight and a 200 watt tungsten lamp. The light from the lamp when filtered through Roundel glass differs from sunlight in its spectral distribution by a very small amount in the violet portion of the spectrum. The calibration was made for each filter by means of a Kingsbury flicker sight box with a special Lummer-Brodhun cube.

The photometer shown in Fig. 2 was constructed to measure the scattering of the light at

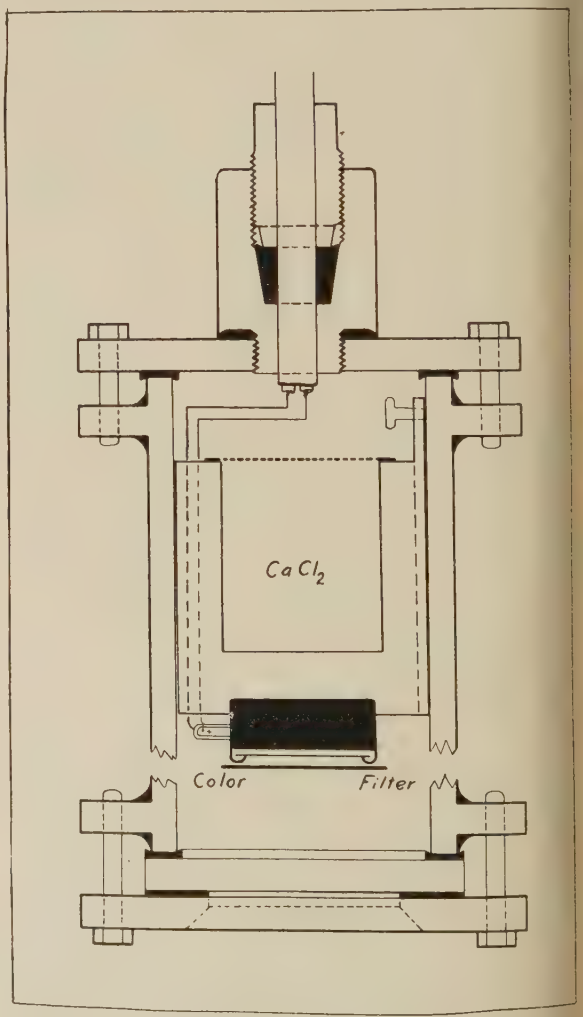


Fig. 2. Photometer for Measuring Scattered Light.

us depths. It consists of a cylindrical steel provided with a flange at each end and closed e upper end with a piece of boiler plate. The end was closed by means of a glass window, plicate of the window used in the photometer ibed above. The cell was mounted on an table support in such a way that the color s could be placed between the cell and the ow.

include the following regions: The San Juan Archipelago, which is located between the mainland of the state of Washington and Vancouver Island, British Columbia; the Strait of Juan de Fuca between Cape Flattery and Port Angeles; Puget Sound; the waters of the inside passage to Alaska; the north Pacific Ocean between the 47th and 50th parallel approximately 150 miles from the shore line of Canada and the United States; and the Pacific

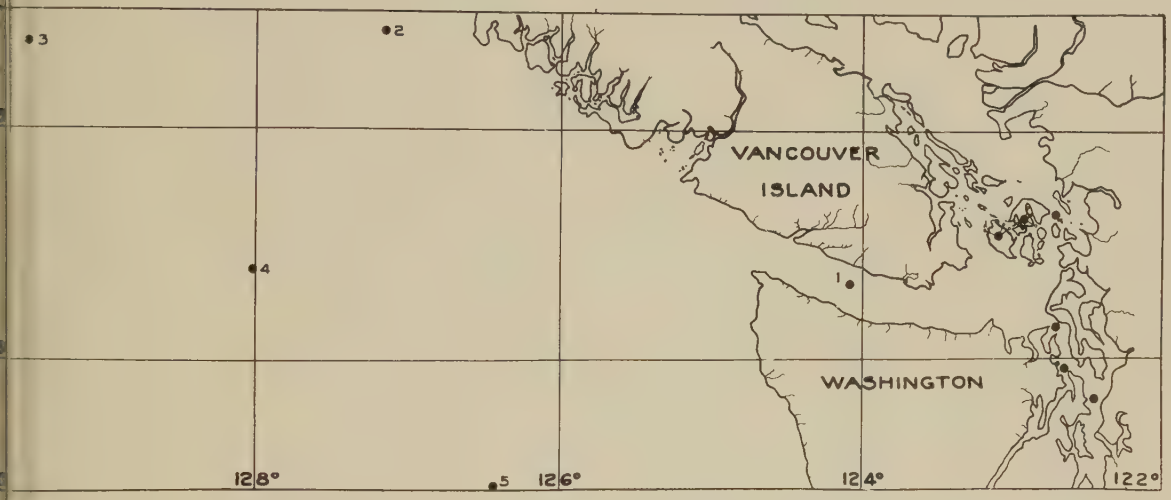


Fig. 3. Northwestern United States and Southwestern Canada.

ven color filters were used in most of the ations on transmission while but three were n the scattering observation reported in this Each filter, with the exception of the yellow was chosen to give as narrow a transmission as possible. The transmission band of the filter was rather wide, extending somewhat he red and slightly into the violet. An ve wave length has been arbitrarily assigned h filter. Former experiments show that the tion in the inshore and near shore waters is n the central portion of the spectrum so the ve wave length of any filter will shift towards nter of spectrum with increasing depth unby chance, the effective wave length of a lar filter happens to be that of least absorpthe water. The shifting of the transmission is quite marked in the extreme red and e violet. However, each transmission band e considered as designating a small region of ectrum rather than an exact effective wave The wave lengths assigned to the color are: 4600 A, 4800 A, 5150 A, 5300 A, , 6000 A and 6600 A.

servations on submarine radiation have been at many stations in the Pacific northwest. ations occupied during the last three years

Ocean off the Oregon and California Coast. The distribution of the submarine radiation at these stations has been computed and tabulated but only characteristic results will be treated in this paper.

The location of many of the stations where observations have been made in the San Juan Archipelago and the Pacific Ocean are shown in Fig. 3 while the location of some Alaska stations is shown in Fig. 4.

The small solid circles in the Figs. 3 and 4 refer to the location of places of observation.

The work here reported may be divided for convenience into three parts. (a) One part consists in a study of the transmission of light through the water in the several different locations. The photometer shown in Fig. 1 was used for all measurements of this type. (b) Monthly observations of the transmission of several spectral bands of light through the water have been carried out during 1934 and 1935 and are being continued throughout 1936. In 1934, one station was located in the Strait of Juan de Fuca about twenty-five miles in from Cape Flattery and another in Hood Canal near the junction of the Canal with Puget Sound. During 1935 the observations were continued at the station in the Strait but not at the one in Hood Canal. The 1936 measurements are being made at

the same locations as were those of 1935. (c) Measurements on the scattering of light were made at selected stations in the San Juan Archipelago.

Measurements of Penetration into the Water.

The penetration of light into the water is indicated in this paper by a quantity, k, which may be called a total vertical absorption coefficient for a narrow spectral band of radiation and which may be defined by

$$I = I_o\, e^{-kx}$$

Where I_o is the intensity of illumination of a particular color just beneath the surface, and I is the intensity x meters vertically downward.

As the numerical value of k is in part determined by scattering by the water and by suspended matter it is not a true absorption coefficient but refers to the removal of radiation by the water for whatever causes may be operative. Atkins and Poole have given an excellent discussion of this coefficient and have found that consistent results could be obtained by its use. Their conclusions have been verified by the writer.

When a series of measurements were to be taken, the photometer, which was attached to a cable wound on an electrically operated drum, was lowered just beneath the surface of the sea. The light filters were then successively placed between the window and the photoconductivity cell and the current produced by the light transmitted through each filter was recorded. As the measurements were made to determine the absorption coefficients for each band of light this condition was taken as the initial one and illuminations at greater depths were compared to this. The photometer was lowered to greater depths and the current, for each filter again recorded.

The thickness of the layer of water between successive positions of the photometer was chosen by a consideration of the light intensity at the surface at the time and by a consideration of the characteristics of the water.

The elcctromagnet, used for operating the aluminum disk upon which the filters were mounted, permitted very rapid shifting of the filters. It has been possible to make a series of 180 observations in less than sixty minutes. Under conditions where it is desirable to measure the relative intensities at five or ten meter intervals, the time occupied in a series of observations is relatively short. This is of considerable importance in that it affords almost simultaneous measurements on various colors at each depth and a very small time interval between observations at different depths. Thus the illumination due to each color may be obtained under comparable conditions.

Southeastern Alaska.

The topographical features of the islands of southeastern Alaska are similar to those of the mainland to the east of them but less elevated. The islands are high, rough and broken. The higher summits are quite irregular and show but little modification by erosion. The lower summits are usually rounded and covered with a dense growth of timber. The midsummer snow line is at an average altitude of 1000 meters. Glaciers are found in many of the gorges and, in the northern part of the archipelago on the continental shore, attain a great size many of which reach to the water. The steep inclines and narrow gorges are continued below sea level and form a complex system of narrow straits which extend from Puget Sound to Cape Spencer.

The prevailing winds are from the southwest in the early summer and from the northwest in July and August. Southeast winds are usually accompanied by rain while northeast winds bring snow. The prevailing winds are clearing winds. In the inlets opening from the ocean, fog is frequent in July, August and September. The fogs, which come after midnight, are usually dispelled by clearing winds before noon.

The results of observations at several stations in southern Alaska are shown in Table 1. With the exception of the station off Cape Spencer, they were all made in the waters of the inside passage to Alaska. All of these waters show considerable evidence of layering of foreign matter which probably results from land drainage and, in some instances, from glaciers.

The water, in some cases, is modified by the discharge of large rivers which have drained considerable land areas. This is especially true at the station off MacArthur Reef, in Sumner Strait, past which flows the discharge from the Stikine River. Here the water enters Sumner Strait over a mud flat which extends from the mainland to Mitkof Island on the west. The ebb makes out from the vicinity of Wrangel through Sumner Strait, Stikine Strait and Chichagof Pass, its velocity being materially augmented by the current from the Stikine River. There is a relatively high absorption in the upper four meters, from four meters to ten meters the absorption is very great while below ten meters the transparency increases. Net hauls at this station showed but little plankton.

A similar condition exists at the station off Watson Rock, which is near the mouth of the Skeena River. The absorption was very great and very little microscopic organisms were found.

Dixon Entrance forms one of the deep water inlets to southeastern Alaska from the sea. It is one of the connecting waters of the inside passage. It extends from Cape Muzon in a northeasterly direction a distance of 60 miles with an average

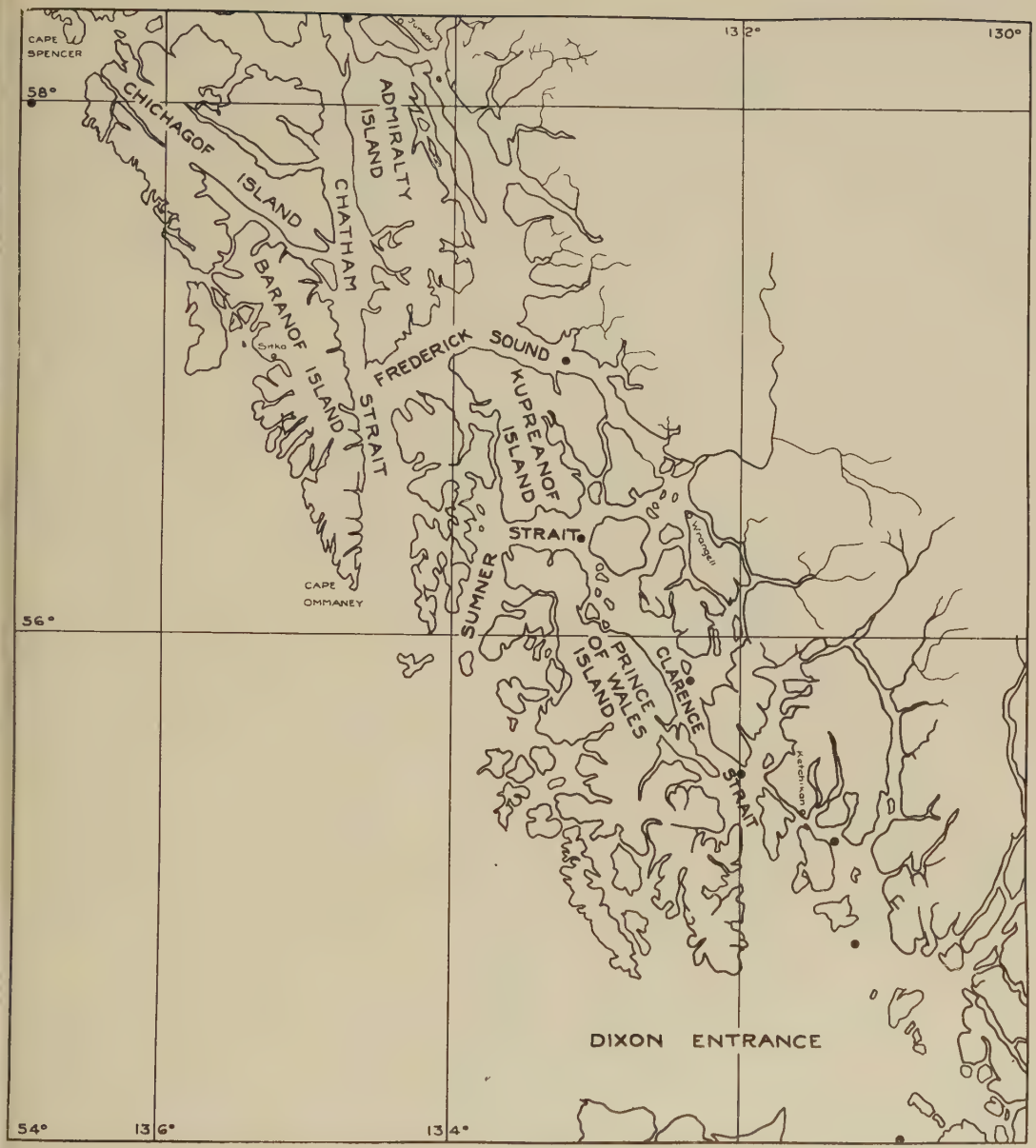


Fig. 4. Southern Alaska.

h of 30 miles. It then contracts to a width of
les and continues with this width to the mouth
rtland Canal, a distance of 18 miles.

he water off Cape Spencer is much more
parent to blue light than are the inshore
r. The sea is entered at the Cape by Icy Strait
Cross Sound. These are the northernmost
nels connecting the inside passages. Glacial
from Glacier Bay is often seen fifteen miles
ard from Cape Spencer.

It will be noticed that in Hecate Strait, and to a lesser extent in Dixon Entrance, the transmission is greater in the blue region of the spectrum than it is in the inshore waters.

In general the transparency of the waters of the inside passage is less than any measured, with the maximum transmission in the green portion of the spectrum.

Table 1.
Per cent. of transmitted Ligth of three spectral Bands in the Waters of Southern Alaska.

Stations	Depth in meters	Per cent transmitted.			Temp. °C.	Cl ‰
		λ = 6000 A	5300 A	4800 A		
Hecate Strait	0	100	100	100	14.30	17.48
	10	0.24	25	19	13.35	17.59
	15	0.021	16	14	—	—
	20	0.0054	7.9	11	—	—
	25	0.0038	4.7	3.4	9.8	17.83
	30	0.0025	3.0	0.34	—	—
	35	—	1.5	0.068	—	—
Dixon Entrance ...	0	100	100	100	12.70	15.17
	5	18	35	26	—	—
	10	1.8	16	7.8	10.01	16.10
	15	0.53	7.6	3.9	—	—
	20	0.27	5.7	2.3	—	—
	25	0.015	1.9	1.0	9.60	17.25
	30	0.012	0.12	0.082	—	—
Off Walker Island.	0	100	100	100	15.00	11.98
	1	60	72	70	—	—
	2	41	65	53	—	—
	3	27	49	38	—	—
	4	18	41	28	—	—
	5	12	32	19	—	—
	6	7.8	25	13	—	—
	7	4.9	18	9.1	—	—
	8	3.1	13	6.0	—	—
	9	2.1	11	1.8	—	—
	10	1.5	9.0	0.33	10.25	15.42
	15	0.35	4.5	0.12	—	—
Off MacArthur Reef	0	100	100	100	10.21	14.25
	1	41	49	39	—	—
	2	21	30	20	—	—
	3	15	25	12	—	—
	4	9.6	18	9.1	—	—
	5	6.0	14	6.1	—	—
	10	0.046	0.28	0.96	8.81	16.62
	15	0.0072	0.13	0.026	—	—
	20	—	0.052	0.0074	—	—
	25	—	0.018	—	7.86	17.28
Portland Island ...	0	100	100	100	9.05	13.69
	5	13	23	18	—	—
	10	0.30	0.81	0.12	9.00	14.35
Watson Rock	0	100	100	100	9.65	10.20
	2	22	15	12	—	—
	4	0.0043	0.45	0.12	—	—
Off Cape Spencer..	0	100	100	100	—	—
	5	13	43	45	—	—
	10	1.7	18	20	—	—
	15	0.22	7.8	9.1	—	—

San Juan Archipelago.

The San Juan Islands form a part of the northern section of the state of Washington, lying t of the Washington mainland, and east of the h end of Vancouver Island, British Columbia, nort distance south of the 49th parallel. The Juan Islands include large and small islands rocks above high tide to a number of 428, of h 175 are large enough to warrant individual es. The archipelago includes a number of hboring islands which are a part of the same eral group. The islands are rocky and hilly. ugh their surface is rocky there are considerareas of glacial till and a number of swamp peat areas. The islands have rocky shores gh some are partly bordered by swamps.

The summers are usually dry and cool and the ers are rainy. The contours are such as to cut the saturated winds from the ocean. The isds together with some portions of the mainland Washington to the east and southwest and the hwestern portion of Vancouver Island have r rainfall than that of other portions of ern Washington and British Columbia.

A detailed survey of the transparency of the r has been made in this region during the last e years and some correlation suggested between plankton distribution and growth and the sparency of the water. The data presented in le 2 is characteristic of the location and illues the marked differences existing in one on.

East Sound, on the south shore of Orcas Island, nds northwest about 7 miles. It varies in width h 2 miles at the north to ½ mile about half up the sound. The depths vary from 16 meters to 27 meters. In the summer East Sound is exceedingly rich in plankton. The water is a dark green color. The water here differs from all the other waters in the Archipelago in that it is not subject to turbulence. There is a very gradual exchange of water between the sound and neighbouring water bodies. The maximum plankton count is in May while after September it falls to an exceedingly low value. The water is warmer than neighboring waters in the summer and the phosphates, nitrates and silica are so low that no color reaction is obtained.

Pole Pass is between Crane Island and Orcas Island just west of East Sound. The plankton are not as abundant as in East Sound. The water averages about 40 meters in depth. The Pass itself is only 75 yards wide. The observation station was located north and west of the Pass well out from shoals which extend from the north shore of Crane Island.

Open Bay is located in Henry Island which lies in Haro Strait immediately westward of the northern point of San Juan Island and separated from it by a narrow strait. The water is about 100 fathoms deep and enters this region, directly from the Pacific, through the Strait of Juan de Fuca on the flood tide. The transparency of the water here is greater than that observed at any other locations in the Archipelago. Measurements at this station were made to a depth of 60 meters but for comparison the transmission is shown to 30 meters.

The North Pacific.

In the late summer of 1934 several series of measurements were made off the coast of Vancouver Island and off the coast of Washington. These measurements were repeated in the summer

Table 2.
Per cent. of transmitted Light of seven spectral Bands in the Waters of the San Juan Archipelago.

Depth in Meters	Per cent. transmitted λ = 4600 A	4800 A	5150 A	5300 A	5650 A	6000 A	6600 A
			East Sound				
1	100	100	100	100	100	100	100
5	14	17	22	29	25	15	15
9	.45	.78	1.6	3.2	3.5	1.1	.27
13	.10	.12	.25	.70	.77	.16	.13
17	—	.043	.050	.20	.22	.023	—
21	—	—	.020	.080	.066	.009	—
			Pole Pass				
0	100	100	100	100	100	100	100
5	19	22	23	29	25	8.9	—
15	.77	1.1	1.9	2.7	1.8	.17	—
25	.04	.09	.93	.34	.23	.03	—
			Open Bay				
0		100		100		100	
10		11		15		1.4	
20		1.4		2.8		.043	
30		.15		.35		.0041	

of 1935, extending farther south, with comparable results. The stations, numbered 1, 2, 3, 4 and 5 on the map, are located as follows:

Station 1 is in the Strait of Juan de Fuca		
Station 2 is	49° 25′ N	127° 09′ W
Station 3 is	49° 22′ N	129° 29′ W
Station 4 is	48° 24′ N	128° 01′ W
Station 5 is	47° 26′ N	126° 26′ W

The absorption coefficients, for each spectral band, are recorded in Table 3. At stations 3, 4 and 5, where the water was a clear deep blue, the absorption of the shorter wave lengths was relatively low in the upper layers of the water, increased to a maximum around 50 meters and then decreased with increasing depths. At each of the stations the richest plankton hauls were made between 40 and 50 meters, a fact which may afford some bearing on the effect of light in controlling the diurnal migration of plankton.

It will be noticed that the absorption of all frequencies is very low compared with that of the inshore waters. Also the minimum absorption is in the short wave length end of the spectrum. This is especially true in the stations located farther to the westward. The average values of the coefficients for station 2, which was 28 miles off shore, are greater than the average values of the three stations to the west, while the average values in the Strait of Juan de Fuca are considerably greater than at station 2, but not as great as for the inshore waters of San Juan Archipelago.

Table 3.
Spectral Absorbtion Coefficients in the Strait of Juan de Fuca and in the North Pacific Ocean.

Station	Depth in Meters	Total Vertical Absorption Coefficient λ = 4600 A	4800 A	5150 A	5300 A	5650 A	6000 A	6600 A
1	0—5	.434	.388	.320	.294	.344	.462	
	5—15	.412	.374	.328	.292	.290	.452	
	15—20	—	.332	.274	.266	.248	.354	
2	0—10	.202	.174	.149	.144	.206	.385	.574
	10—15	.138	.170	.136	.170	.166	.304	
	15—20	.137	.096	.144	.090	.108	.284	
	20—25	.060	.064	.088	.092	.132		
	25—30	.059	.060	.073	.080	.074		
	30—35	.058	.048	.072	.071	.096		
	35—40	.058	.072	.071	.068	.096		
	40—45	.024	.026	.072	.040	.140		
	45—50	.040	.036	.080	.086	.084		
3	5—10	.104	.054	.046	.062	.116	.306	.570
	10—20	.091	.086	.093	.105	.110	.286	
	20—30	.079	.065	.070	.076	.091		
	30—40	.059	.084	.090	.083	.092		
	40—50	.071	.062	.043	.072	.066		
	50—60	.047	.053	.055	.060	.096		
	60—70.5	—	.063	.070	.089	.089		
4	0—10	.054	.018	.033	.037	.100	.249	.451
	10—20	.041	.064	.035	.060	.083	.291	
	20—30	.130	.099	.105	.106	.109	.156	
	30—40	.162	.170	.146	.146	.149		
	40—50	.104	.101	.097	.106	.118		
	50—60	.118	.069	.085	.083	.095		
	60—72.5	—	.032	.030	.027	—		
5	0—10	.081	.088	.063	.094	.148	.338	.488
	10—20	.047	.041	.056	.049	.103	.226	
	20—30	.058	.039	.055	.055	.076	.167	
	30—40	.087	.099	.065	.089	.097		
	40—60	.090	.081	.079	.086	.081		
	60—72.5	.105	.081	.082	.095	.103		

Seasonal Variations in Absorption Coefficients.

During the year 1934 monthly measurements made on the absorption of seven spectral ds of radiation. One of the two stations se- d for these observations was Pillar Point h is located in mid channel of the Strait of de Fuca, twentyfive miles in from Cape ery. This station is at the head of a submarine n which extends out from the Strait and gh the Continental Shelf. Beyond the shelf is considerable evidence of upwelling which tidal and non-tidal currents produces a general ulence and results in considerable mixing of waters. The water is a greenish blue color upper layers being somewhat like Puget Sound r, while the lower layers are more oceanic in acter.

of total plankton with transparency at the station in Hood Canal. The plankton study, at the time of writing, is not completed.

In Fig. 5 and Fig. 6 curves *A*, *B* and *D* show the absorption coefficients for the first 10 meters, while curves *C* and *E* show the absorption coefficients from 10 to 20 meters. *A* is for 6000 A, *B* and *C* are for 5300 A and *D* and *E* are for 4800 A.

The results of the 1935 study at Pillar Point show considerable differences when compared with those of 1934. A maximum absorption in the upper layer occurs each year. It was earlier in 1935 than in 1934. The 1934 maximum of absorption was coincident with a maximum in the total plankton. The curves for each year exhibit a minimum in December.

Since the values of the absorption coefficients are due to properties of inorganic matter as well as organic matter, the observed variation in coeffi-

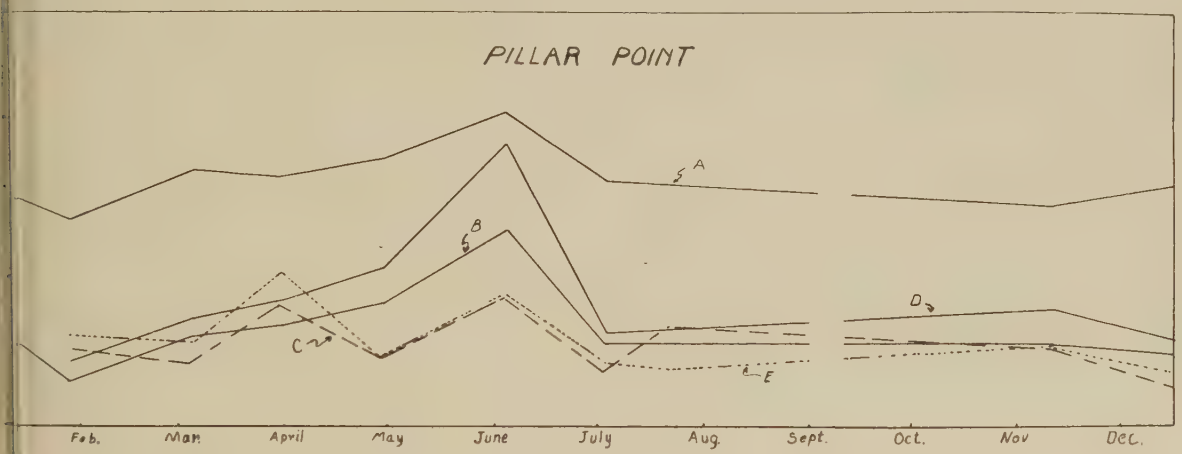


Fig. 5. Variation in Absorption Coefficients at Pillar Point during the Year 1934.

he other station is located at the junction of Canal and Puget Sound. The water is about meters deep, is of a dark greenish color and ins more organism and suspended matter than r Point. The water has many of the charac- ics of fjord water. During 1935 these monthly vations were repeated. However, a station in Sound at Point No Point was studied instead e one at Hood Canal, as it had been found uit to reach the Hood Canal station at a time able for making radiation measurements. water at Point No Point was similar in cter to that at Hood Canal.

he variations in the absorption coefficients of of the spectral bands at the Pillar Point n for the year 1934 are shown in Fig. 5. Of ata available on total plankton at this station is some evidence of correlation with the parency. There is more evidence of correlation

cients is caused by changes in the amount and kind of matter present in the water.

The observations were made to depths of 50 meters during most of the year but due to the exceedingly low intensity of daylight in the winter months, comparison data for the first 20 meters are shown. Some of the winter data were taken during fog or rain and on some days, the surface of the water was not as quiet as was often experienced in the inshore waters.

Scattering of Subsurface Radiation.

While a considerable number of observers have been concerned with the transmission of daylight through ocean waters, there has been very little work done on the light which is scattered at various depths.

In order to investigate the light scattered in certain spectral bands the photometer shown in

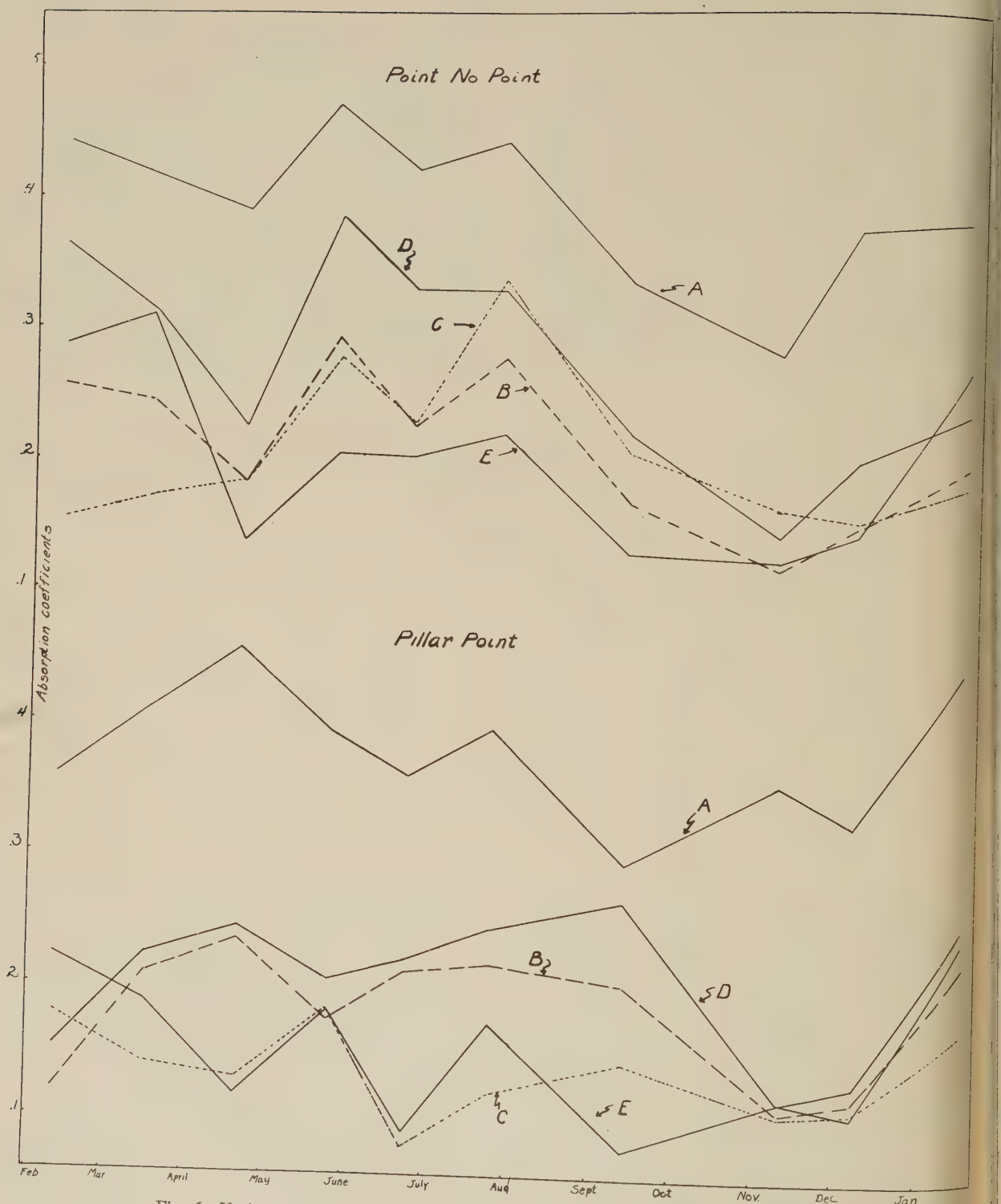


Fig. 6. Variation in the Absorption Coefficients at Point No Point and Pillar Point during the Year 1935.

2 was constructed. The experiments reported were conducted in the waters of the San Juan pelago in the late summer af 1935. A station elected such that the depth of the water was ximately 40 meters.

ith one of the filters between the cell and the w and with the window downward, the photo-, suspended by a cable, was lowered until the w was six inches beneath the surface of the and the current measured. It was then ed by 5 meter intervals as deep as the in- of the upward scattered light could be ately recorded. The photometer was next by the same 5 meter intervals and the cur- measurements repeated. The photometer was suspended on the cable so that it was hanging ally but this time with the window upward d of downward as before. A similar series of rements gave the relative intensity of the ward transmitted light at the same depths. measurements were repeated for each of the and, at all times, simultaneous observations - inntensity of the light incident upon the e were made with the deck photometer, ed with the proper filter. The current rements were made with a galvanometer had a sensitivity of $98 \cdot 10^{-6}$ microamperes. e relative intensities of the downward trans- light and of the upward scattered light for ilter were plotted on a logarithmic scale and these graphs the data for Table 4 were ted.

e intensity of the transmitted light and the ty of the upward scattered light, at the dif- depths, was computed in terms of the 6 inch face light and expressed as per cent. of that 6 inches below the surface. The values of the ratio of the scattered light to the transmitted light for each color are shown in Fig. 7.

The observations were made under very ideal conditions. There were no clouds in the sky and the intensity of the incident light was exceedingly constant during each series of measurements.

The comparison of scattered to transmitted light shows variations which, no doubt, are due to the nature of suspended matter and organisms in the water. The relatively low scattering of red light near the surface may be explained to some extent by the absence of organisms which are found at greater depths and which are known to reflect the longer wave lengths. It may also be explained, in part, by the fact that the longer wave lengths of the light transmitted through the red filter are absorbed largely near the surface.

Discussion of Results.

Since a thorough review of the literature has been made by Atkins and Poole and by Clarke and Oster, no detailed comparison of the work of other investigators will be presented in this paper.

There are certain possible sources of error to be considered in making submarine radiation measurements at sea. The shading caused by the ship might be considerable in the upper layers of water and can be lessened by having the photometer as far from the ship as possible with the ship away from the sun. The effect of the ship exists when observations are made with overcast skies. Many of the observations reported here were

Table 4.

Per cent. of transmitted and upward scattered Light of three spectral Bands.

Downward traveling Light								
$\lambda = 4800$ A			$\lambda = 5300$ A			$\lambda = 6000$ A		
Relative Intensity I	$\log_e$ I	% of I at .15 m.	Relative Intensity I	$\log_e$ I	% of I at .15 m.	Relative Intensity I	$\log_e$ I	% of I at .15 m.
18500	9.83	100	72100	11.19	100	156000	11.96	100
6990	8.85	38	29300	10.29	41	15000	9.62	9.6
2620	7.87	14	11800	9.38	16	1980	7.59	1.3
992	6.90	5.4	4780	8.47	6.6	340	5.83	.22
372	5.92	2.0	1920	7.56	2.7	73.2	4.29	.047
141	4.95	0.76	781	6.66	1.1	19.9	2.99	.013
—	—	—	321	5.77	0.44	6.17	1.82	.0039
Upward traveling Light								
351	5.86	100	713	6.57	100	347	5.85	100
145	4.98	41	347	5.85	49	90.3	4.5	26
58.7	4.07	18	161	5.08	26	23.6	3.16	6.8
22.9	3.13	6.5	71.7	4.27	10	6.18	1.82	1.8
8.59	2.15	2.4	30	3.40	4.2	1.63	0.49	0.47
2.89	1.06	.82	12.1	2.49	1.7	—	—	—
0.91	—0.09	.26	4.81	1.57	0.67	—	—	—

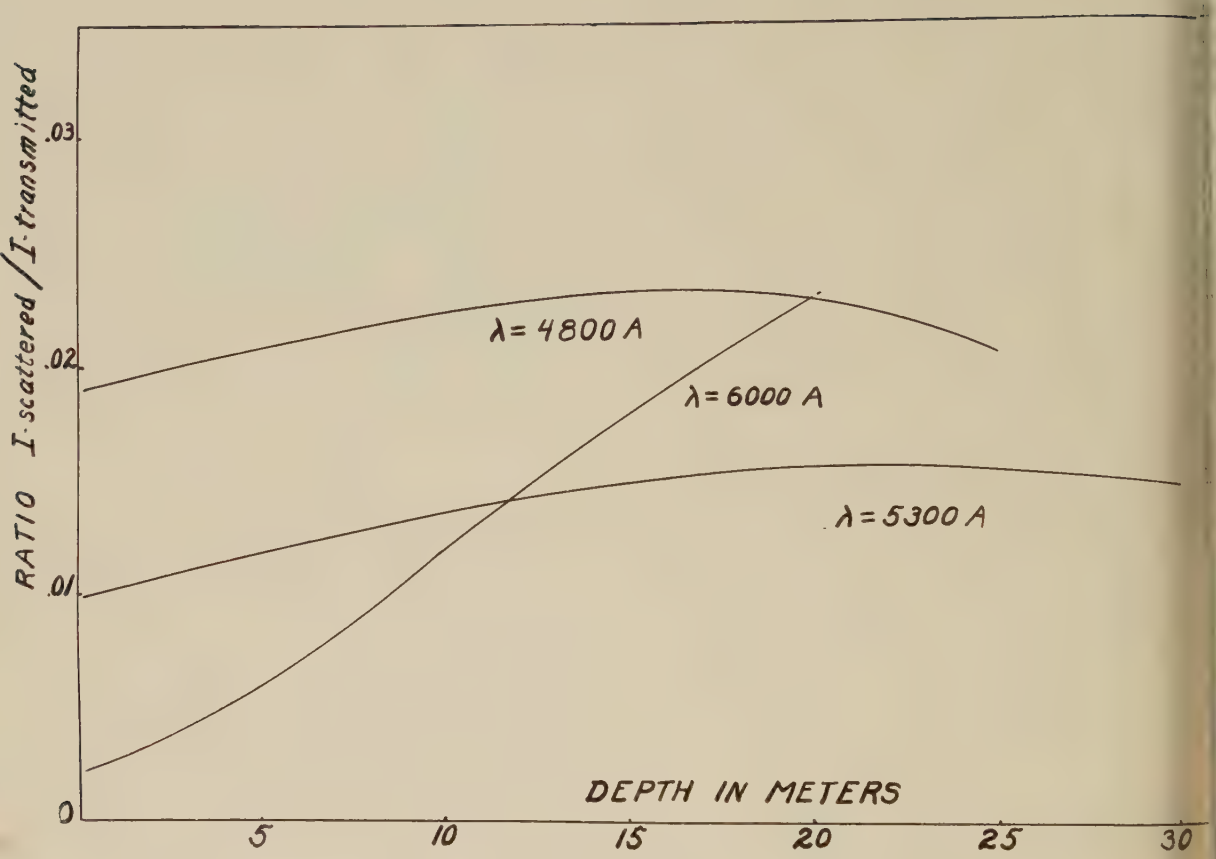


Fig. 7. Curves showing the Ratio of upward scattered Light to transmitted Light.

made when the incident light was well diffused and very constant, though of low intensity.

An error of considerable magnitude may be introduced by changing conditions in the water column above the photometer. This is especially serious in the inshore waters where tidal currents are experienced. It is, therefore, desirable to complete a series of observations in the shortest possible time, in order that the intensity of each color at the different depths may be determined under comparable conditions. Variations in surface reflections also afford a source of error. A large percentage of the observations reported here were made under ideal surface conditions. In the San Juan Archipelago, in Alaska and at times in the Pacific the surface was very smooth. When rough surfaces are encountered variations in the depth of the photometer due to the roll of the boat offer a source of uncertainty. This may be of considerable magnitude if the photometer is suspended a few meters out from the rail of the boat.

Since the extreme ends of the visible spectrum are more highly absorbed by water than the middle portion, there is a considerable variation in the spectral distribution of the light with depth and thus the values of absorption or scattering coefficients may depend greatly on the manner of making the measurements. The amount of energy transmitted through, or scattered by, a layer of water depends not only on the magnitude of the energy present, but on its spectral distribution and on the nature and amount of suspended matter in the water. Very different results will be obtained if the total energy is measured rather than the energy of narrow spectral bands.

Various statements are found in the literature suggesting some correlation between the abundance and distribution of plankton in the sea and the transmission of light, or a lack of such correlation. (Shelford and Gail; Atkins and Poole; Pettersson; Petterson, Höglund and Landberg; Clarke and Oster, etc.). Re-

of other investigators are matched by instencies in our own data. It would appear us that the effect of plankton on light transon would be a function not only of the amount ankton present but also on its transmission reflection characteristics. In certain cases, at the absorption attributed to plankton may ue to totally unrelated factors such as tur, etc.

so far as the biological significance of sube radiation is concerned two factors must be ered. First, the total illumination, both in cter and intensity, is the effective factor in mining the growth and abundance of phototic organisms. Second, the direction of the as well as frequency and intensity is the ive factor in determining the distribution of organisms whose movements are affected by rface radiation.

ere are but little data available on the e values of direct and scattered light. A very examination of water bodies, repeated at reintervals and including simultaneous observations of scattering and transmission of narrow spectral bands of radiation, will afford valuable information on the influence of light on growing organisms below the surface. An examination should, of course, include a simultaneous investigation of the number and kind of suspended particles and their optical characteristics with respect to the spectral distribution of the radiation at the depths where they are found.

References:

V. E. Shelford and F. W. Gail, Publication of Puget Sound Biol. Stat. 3, 141, 1922.

W. R. G. Atkins, Journal du Conseil, VII, 2, 171, 1932.

W. R. G. Atkins and H. H. Poole, Phil. Trans. Roy. Soc. Dublin, B 478, 129, 1933.

George L. Clarke and R. H. Oster, Biol. Bulletin 67, 59, 1934.

Hans Petterson, Hans Höglund and Svante Landberg, Medd. från Göteborgs Högskola, No. 10, 1934.

Hans Pettersson, Göteborgs Kungl. Vetenskaps- och Vitterhets-Samhälles Handl. B 4, 5, 1934. Journ. du Conseil X, 1, 47, 1935.

5.

ON THE UNIT FOR RADIATION IN OCEANIC RESEARCH.

BY

ANDERS ÅNGSTRÖM,
STOCKHOLM.

HE measurements of the radiation have, in the last twenty years, attracted a growing interest within the geophysical science. Espe within the meteorology, which deals with the cs of the atmosphere, the radiation processes f fundamental importance, as it is through the ion from the sun that in the last instance all sses within the atmosphere arise. As within the rology, the interest in the first hand attaches to the radiation as vehiculating a *transport ergy*, it seems natural that the common units easuring energy have been adopted also for ring radiation within this field: watt, or, now ost general use: the *gram calory per square eter per minute.*

e use of the latter unit has the advantage e, through the simplest possible calculations, le to obtain an idea from the radiation as to se in temperature which the radiation is pro- when absorbed. The unit gram calorie per centimeter per unit of time, is therefore, we are dealing with problems as regards the s of the atmosphere, *natural and practical.* e conditions as regards the most practical re not quite as simple when we leave the al meteorology and take into consideration re statistical part of the same science namely *matology.*

e of the chief tasks of climatology consists ishing the necessary data demanded for the e of technical or scientific investigations. If k at the measurements of radiation as a *logical element*, there are a number of spe- esearch-fields, which demand that the data nay be applicable to their special problems. or illumination studies, we wish the clima- to give us the natural illumination from sun y, the physician wishes to know the intensity groups of wave lengths, which exercise a eutic influence, the biologist demands in- ions as regards the kind of radiation, which influence for instance upon the assimilation or growth of plants. It is evident that for these various kinds of investigations it is not always natural and in practice convenient to use the energy unit at measurements of the radiation. For illumination purposes one has thus early introduced a special unit: the lux. As regards therapeutics, one has sought to define the light intensity directly through its erythem effects. In a similar way one can imagine different definitions on the basis of various actions, every unit within its special field of research.

The principle to use within different fields of investigations different units for radiation, has however, on the side of undeniable advantages, also important drawbacks.

It is evident, that we must demand from the radiation measurements, which are intended for a general applicability, that they are booked in such a form, that they without troublesome computation by means of constants — frequently difficult to find — may be applied to a number of various problems. This is the reason why we have, within the climatology and adjacent fields of research, almost generally adopted *an energy unit* for the radiation, whereby naturally it is necessary to add a clear definition of the interval of wave lengths in question. In this connection I may refer to the resolution passed by the 2nd International Light Congress in Copenhagen, 1932, as regards the unit for light within the medical field:

Article I. De recommander la standardisation des sources utilisable en médecine en subdivisant le spectre ultraviolet en trois tranches spectrales définies provisoirement par les filtres suivantes proposés par M. C o b l e n t z — — —

Pour chaque tranche spectrale définie par ces filtres, la mesure du rayonnement devra être fait avec un récepteur non selectif et exprimée de préférence pour les mesures médicales ou météorologiques en milli-calories grammes par cm. carré et minute (Comptes-Rendus du 2-ème Congrès International de la Lumière, Copenhague).

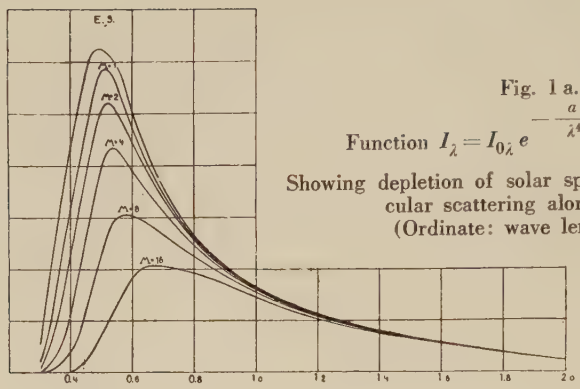


Fig. 1 a.

Function $I_\lambda = I_{0\lambda}\, e^{-\frac{a}{\lambda^4}\cdot m} = I_{\lambda 0}\cdot q_1^m$

Showing depletion of solar spectrum through molecular scattering alone. ($h = 0$)
(Ordinate: wave length in μ).

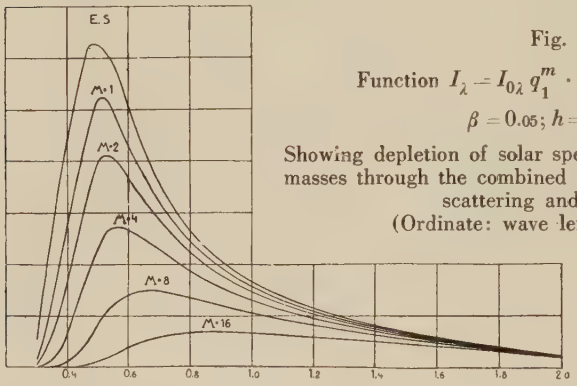


Fig. 1 b.

Function $I_\lambda = I_{0\lambda}\, q_1^m \cdot e^{-\frac{\beta}{\lambda^{1.3}}\cdot m}$

$\beta = 0.05$; $h = 0$.

Showing depletion of solar spectrum at different air masses through the combined influence of molecular scattering and dust.
(Ordinate: wave length in μ).

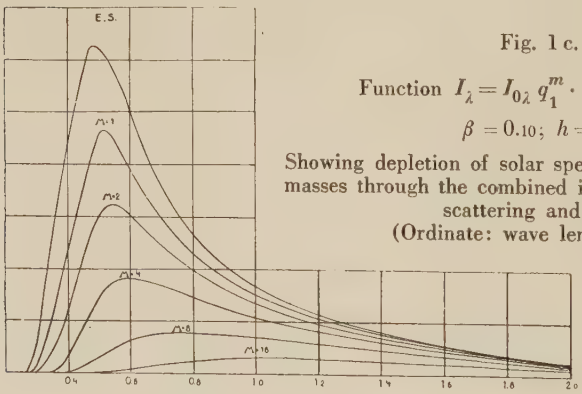


Fig. 1 c.

Function $I_\lambda = I_{0\lambda}\, q_1^m \cdot e^{-\frac{\beta}{\lambda^{1.3}}\cdot m}$

$\beta = 0.10$; $h = 0$.

Showing depletion of solar spectrum at different air masses through the combined influence of molecular scattering and dust.
(Ordinate: wave length in μ).

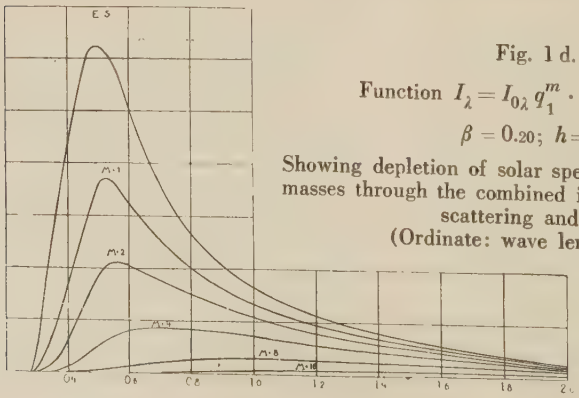


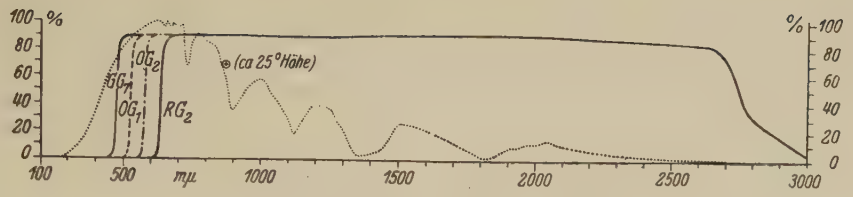
Fig. 1 d.

Function $I_\lambda = I_{0\lambda}\, q_1^m \cdot e^{-\frac{\beta}{\lambda^{1.3}}\cdot m}$

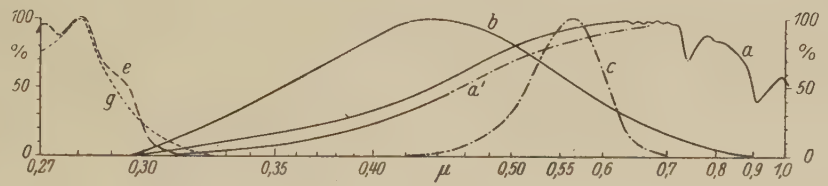
$\beta = 0.20$; $h = 0$.

Showing depletion of solar spectrum at different air masses through the combined influence of molecular scattering and dust.
(Ordinate: wave length in μ).

Fig. 2.



The filter for calorymetric radiation measurements from Dr. F. Albrecht.



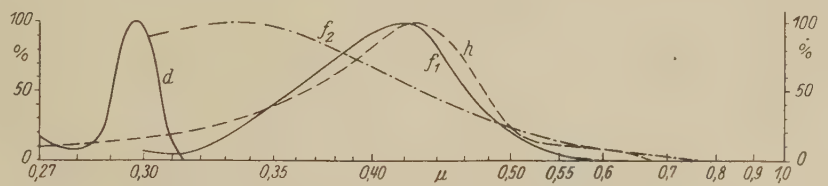


Fig. 3.

Spectral distribution curves of special importance to meteorological photometry. They give the relative spectral distributions; of the intensities of direct sun radiation at an altitude of 30° (a) and 15° (a′) in relation to wave length; of the diffuse spheric radiation (b); of the eye sensitiveness (c); of the radiations forming erythem and ergosterine (e); of the sensitiveness of unsensitized calcium cells (f); of the cadmium cell (g); and of the photographic plate (h). (From Dr. F. Albrecht).

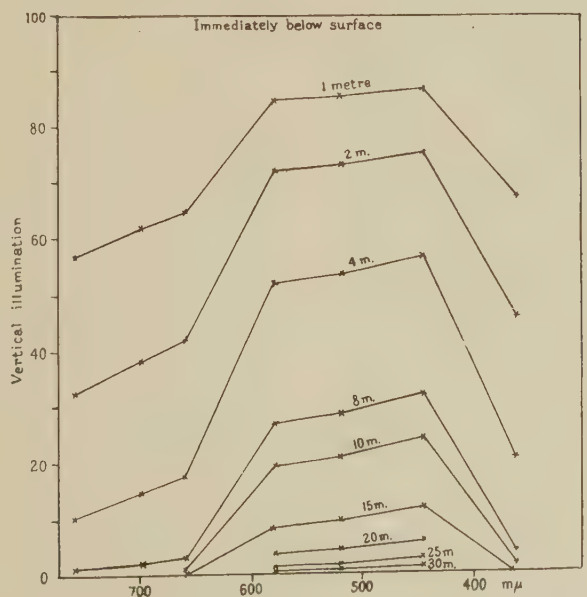


Fig. 4.

Spectral distribution of radiation penetrating in sea water according to Atkins and Poole.

If we consider the radiation measurements within the oceanography, the point of view as regards the unit to be chosen coincides in many respects with the one which has been adopted concerning the climatological radiation field. The reason that the unit *lux* here has acquired a certain popularity is evidently related to the fact that the natural radiation emanating from the sun almost exactly as its spectral extension is coinciding with the visible spectre, as soon as one comes down to depths of more than 5 metres or so. Consequently at these depths with good approximation we can put the radiation measured in *lux proportional* to the radiation measured in energy units as far as the *total* penetrating radiation is concerned. It can therefore seem to be a matter of taste, whether we wish to use the one or the other kind of units for expressing it quantitatively. But the disanvantage of the *lux*-unit is evident, when it comes to a comparison of spectrally different ranges of wave lengths with one another.

The following arguments seem therefore to me to be founded on facts, which are clearly established.

I. If we are measuring the radiation in *lux*, it seems to be a necessary condition that the sensitiveness of the measuring instrument is distributed on the different wave lengths in about the same way as the sensitiveness of the eye. If both are exactly coinciding, we may regard the instrument as a kind of artificial eye, its indications being, under all conditions, proportional to the intensity of the illumination.

An adoption of the *lux* for expressing the results is here natural and reasonable. The drawback shows itself, however, clearly if we wish to compare the indications of the instrument in question with those of another instrument, which is sensitive for instance only within the interval 600—700 μμ or in still higher degree if the new instrument is sensitive only for waves lying outside the sensibility range of the eye, for instance between 300 and 400μμ. We have then no possibility of making a comparison without transferring at first the indications of both instruments into a unit which is liable to be common for them both.

II. A standardization of an instrument for measuring radiation, characterized by selective sensitiveness for various wave lengths, ought appropriately to be made with the aid of a source of radiation which has the same or a similar spectral composition as the radiation which is to be measured. If the instrument is intended for measurements of the natural light, penetrating i the oceans, it is in many cases appropriate to the sun radiation itself for standardization. T following circumstances are in favour hereof:

(1) Exact and easily applied instruments are present available for measuring s radiation with an accuracy of about 1 per cent.

(2) The spectral distribution within the s radiation, which has passed the atmosphe is not quite constant, it is true, and t includes naturally some disadvantage. E the spectral distribution may, as I ha shown at another place, be easily defin through simple integral actinomet measurements.

(3) The sun radiation can easily by means diffusing glasses and the hole-filter, intr duced by H. Pettersson, be reduc to a desired small per cent. of its initi value.

If the standardization is made by means of t natural sun radiation, the unit gram calory p cm.$^{-2}$ and min., or hundredths or perha thousendths thereof, is the most appropriate one.

As regards the spectral distribution of the sens tiveness of the most common radiation instrumen used in oceanographic research, namely the phot electric cells, I would like to add the followin remarks.

III. As soon as the general form of the spectra characteristics of instrument is known with enoug accuracy one can often, for practical purpose apply a more summaric way of investigating th sensitiveness in the special case. I would like t recommend for this purpose the standard glas filters now introduced generally in meteorologica research, namely the Schott filters: OG_1 OG_2 RG etc., which cut out, with almost rasor sharp limit certain regions of the spectre. One can consequentl with the aid of these filters, to a large exten define the sensitiveness of an instrument in dif ferent spectral regions through measuring the per centage decrease of the reading, caused by the in troduction of the filter, in the case of a radiatio source of known wave length. In this way we may in the case of a certain standard type of instru ment (for instance a selenite or a copper oxide cell) determine the average sensitiveness for certain chie groups of wave lengths, as well as control th changes, which may occur, through a simple an convenient method.

6.

THE TRANSPARENCY OF SEAWATER.

BY

HANS PETTERSSON,
GÖTEBORG.

THE transparency of sea water has a twofold importance. Firstly it is the factor, which determines the strength of submarine illu-tion for any given intensity of the daylight ent on the water surface. Consequently parency also limits the depth of the produc- surface-layers, where the photosynthesis of ne algae and phyto-plankton still gives a ive yield. Secondly, transparency observa- afford a measure of the amount of solid cles present in the water, which, leaving in- ic detritus aside, can be considered as po- al food for marine organisms. For both ns measurements of the transparency of sea have considerable interest both to physical ography and to marine biology.

he traditional method of measuring the trans- ncy of sea water which makes use of the ni disc or of some similar contrivance, lowered the sea at daytime until it just disappears and d again until it becomes barely visible, is very e and admittedly only gives a rough indication he transparency of the water relatively near urface. Thanks to the advent of photo-electric and more recently of "photo-elements" (recti- cells) it has become possible to measure arine illumination down to moderate depths to work out mean values of the "vertical ction coefficient", as defined by A t k i n s and l e, for the columns of sea water lying be- the depths in which measurements are made. t from the errors inherent in subsurface light urements, due to variations in the incident day- to wave-motion and to shadowing effects from ull of the ship[1]) the method suffers from the ations set by turbid surface layers to daylight urements with the Secchi disc. Further, the l variations in spectral composition which day- undergoes with increasing depth, makes the extinction coefficients worked out from such measurements not strictly comparable *inter se*, unless the measurements are made with filtered, nearly monochromatic light, which again further reduces the depth to which measurements may still be carried out. Finally, owing to the highly diffuse character of subsurface daylight, the vertical extinction coefficient does not refer to any well-defined length of path of the lightrays, since their majority is more or less oblique to the vertical.

A special instrument designed for measuring *in situ* the transparency to electric light of a column of sea water of sharply defined length was constructed in Bornö Station some years ago and has since then been used on board our research ship "Skagerak". Since the "transparency-meter" has already been shown to this Council in 1934 and has been described in the *Journal du Conseil*[1]), it may suffice to recall the principle of its construction (Fig. 1 a). A slightly divergent cone of electric light is sent out into the sea water through a plate-glass window from an autocar-lamp behind a hemispherical lens. The beam is reflected against a mirror 100 cm. distant from the window and returns to a second window, where it impinges on a photo-element, a rectifying selenium cell from Dr. B. L a n g e. Keeping the lamp-current constant, the photo-current from the cell gives a measure of the transparency of the 2 metres length of sea water through which the light passes. Reading the photo-current produced in air, before the instrument is immersed, one can compute values for the extinction coefficient of the water at each depth where readings are taken. Recent modifications in the construction are: (a) the introduction of a second cell exposed behind a milk-glass to the direct light from the lamp, enabling the observer to correct the readings with the "water-cell" to constant emission from the lamp; (b) a more robust construction of the envelope and taking the windows from "securit" glass makes it possible to use the transparency-meter also at

On board of the new Swedish research ship "Skage- an arm 7 metres in length is mounted from the stern eans of which light measurements can be carried out a minimum of shadows from the hull.

[1]) Vol. X, p. 48.

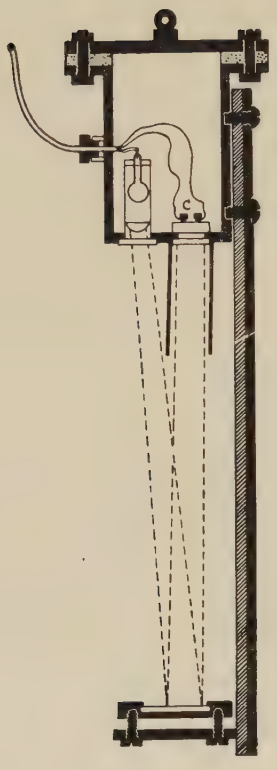


Fig. 1 a.

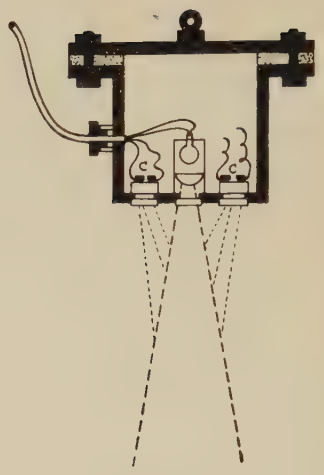


Fig. 1 b.

greater depths. The cable used with the new instrument has 5 leads instead of 4, as with the older, I-cell instrument. The transparency-meter is preferably to be used in a horizontal position, when the transparency of a water layer only 15 cm. thick may be measured.

Observing the photo-current on a high-sensitive "light-spot" microammeter from Siemens & Halske or a "multiflex-galvanometer" from B. Lange, while the instrument is being lowered with the lamp-current on, an examination of the optical properties of the sea water at different depths can be made very quickly. In Swedish fjords very abrupt variations in the transparency with depth are as a rule found, the photo-current changing by 50 % or even more within a sheet of water less than 1 metre thick. A sudden drop generally occurs at the density boundary, revealing a "cloud" suspended particles, plankton or organic detritus, which accumulated there. A rise in transparency is very often found at the level of the threshold of the fjord, below which the water is more or less stagnant, leaving time for the suspended particles to settle.

Measurements with the transparency-meter appear to be the quickest way of locating layers of special interest to the plankton biologist. They can be carried out at any time of day or night, independant of surface-illumination, and also beneath a turbid surface layer almost impermeable to daylight, such as one often encounters in our fjords. Since the spectral composition of the light beam leaving the first window always remains the same, the values of the extinction coefficients found at different depths are always comparable *inter se*, which is not the case with those computed from daylight measurements. Finally the beam of electric light is much more sensitive to the scattering effect due to suspended particles than subsurface daylight, with which scattering is largely compensated through back-scattering.

The "scattering-meter" (Fig. 1 b), also constructed at Bornö, affords evidence supplementary to that given by the transparency-meter. Thus where reduced transparency to light is due to suspended particles, the scattering-meter, which reacts only to light scattered backwards from a strong beam of light against particles suspended in the surrounding sea water, will give an increased photo-current. Where on the other hand reduced transparency is due to dissolved coloured matter, no corresponding increase in the scattered light will occur. In the open sea such substances are no doubt a rare occurrence, but in fjords and still more in lakes, where the run-off water will carry a certain amount of humus, this may form a contributory cause to the extinction of light.

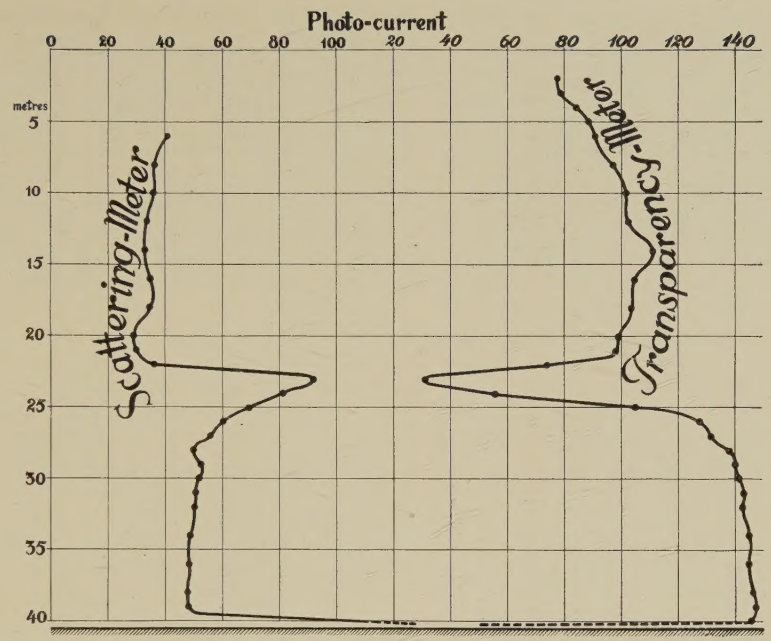


Fig. 2.

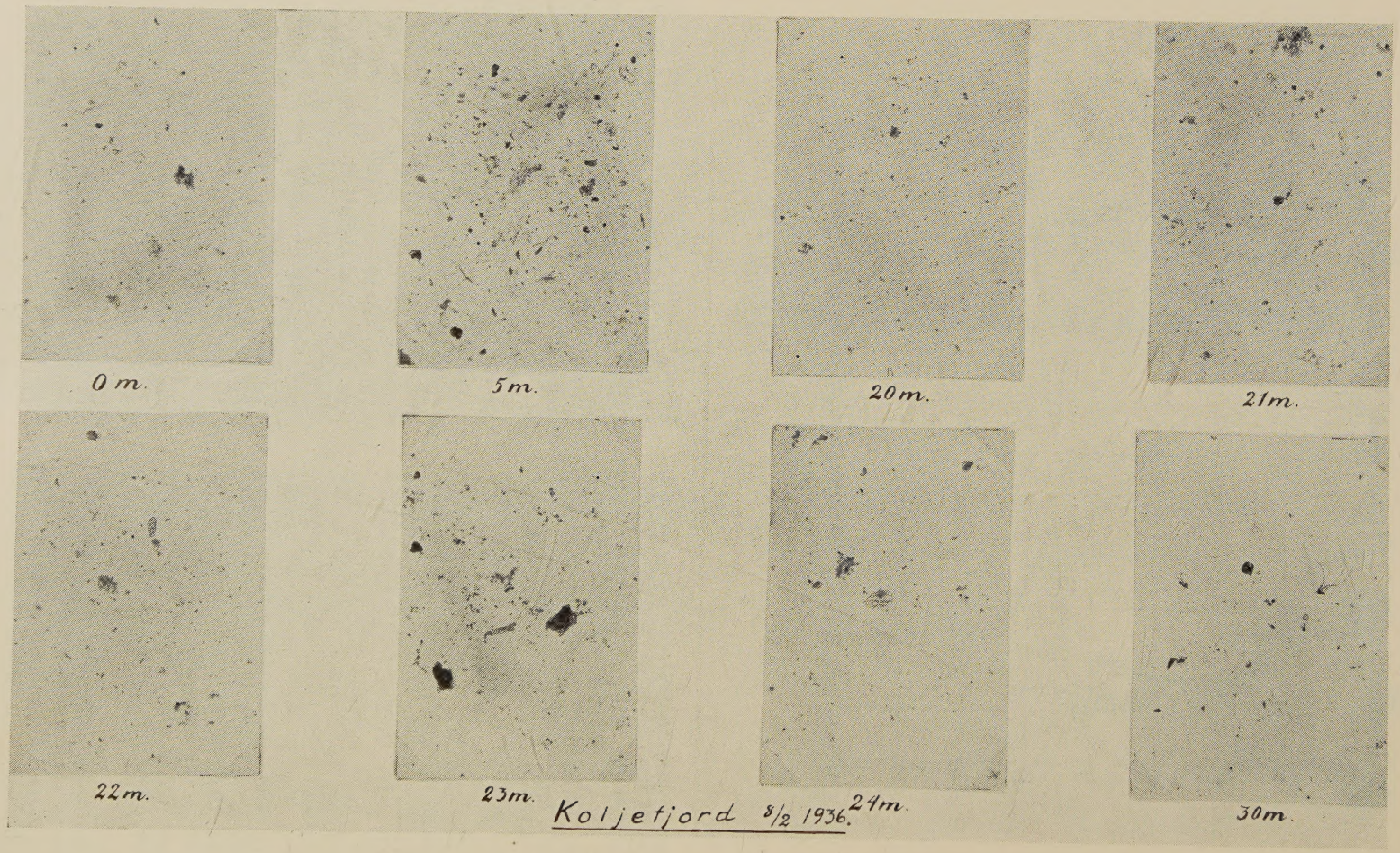
Both instruments may be used with colour-filters duced, either in the way of the emergent lamp- or else before the cells, so that the trans- ncy of sea water to light of different spectral position may be studied. It was hoped in this to arrive at a better definition of the nature of scattering particles, i. e. to find out whether are organic detritus or plankton or inorganic tus from the bottom or from rivers, but the rience so far gained is much too limited to w of any definitive conclusions in this respect. s an example of results obtainable with these instruments[1]), graphs showing the variations ansparency and in scattering with depth in one ur most secluded fjords, the Koljefjord, to the f the large island Orust, west coast of Sweden, reproduced in Fig. 2. Since the measurements made in day-time, the scattering-meter, owing ffuse daylight, was not used nearer the surface in 6 metres. Both curves show an upper and ver layer of nearly homogeneous optical pro- es separated by a very sharp drop in the parency curve and a corresponding rise in the scattering curve at 23 metres. At this depth there was also a considerable rise in salinity, a "density boundary".

In order to find additional evidence for the presence of scattering particles[1]) at this optical boundary, Lic. H ö g l u n d, plankton specialist to our Commission very kindly undertook to take micro-photographs of the particles accumulated in sedimentation cylinders from water samples, taken at certain depths. A series of such photographs is reproduced in Fig. 3 where the sample from 23 metres is seen to contain large and very opaque particles, obviously *débris* from algae, whereas both the samples from 22 and from 24 metres are seen to contain much less. Curiously enough there appeared on the sedimentation micro-photograph from the sample taken in 5 metres a second maximum of particles which were however relatively less opaque in character and to which no corresponding change is discernible in the transparency curve.

It is worthy of attention, that whereas the transparency of the upper layer in the fjord is distinctly *lower* than that of the deeper layer below the particle cloud at 23 m., there is no corresponding difference in scattering, in fact the scattering curve indicates that the upper layer is poorer in

A recent construction will enable us to send down ansparency-meter and the scattering-meter as one unit g use of a 6-lead cable and measuring the trans- cy to one direction and scattering to the opposite ion in the same water layer.

[1]) Mainly organic detritus plankton of all kinds being comparatively scarce at this occasion.



(Microphoto, Höglund).

pended particles than the lower layer. To some nt this deviation from the general rule of an symmetrical trend of the two curves may pos- y be due to a difference in size between the ticles suspended within the two water layers. It ms however more plausible to assume the upper r to be richer in humus from the shore than the er in the lower layer, which must be largely ved from the sea outside the fjord.

The same cloud of suspended particles was nd also in the fjords inside Koljefjord, viz. in vefjord and Havstensfjord, where it was found e quite as pronounced but to occur at slightly er levels, viz. at 24 and 25 metres respectively. surements with orange filter and a blue-green light filter inserted before the cells, which were carried out, gave results very similar to those nd with the electric light unfiltered.

It is of further interest to notice, how remark- y clear the bottom water of the Koljefjord is within less than 1/2 metre from the surface of very fine sediment covering its bottom. This ves that the water must for a very long time e been absolutely stagnant, allowing even the st particles time to settle, a fact which is further borne out by the low oxygen content normal to the bottom water in these fjords.

As a remarkable contrast to these results observations made a few days before in the open Skagerak near the place where it attains its greatest depth, may also be quoted here. The transparency-meter was lowered to within 25 metres of the bottom at 525 metres. The transparency did not vary very much from surface to bottom, attaining its maximum at about 250 metres. But the influence of the bottom sediment in the shape of a decreased transparency here made itself felt already 50 metres above the bottom. The transparency-meter thus furnishes evidence regarding the state of motion near the bottom.

Further studies along the lines here set out will afford information on the amount and location of potential food stuff suspended in coastal waters which is of interest to the biologist and also, perhaps, where daylight measurements are difficult or impracticable, to allow the oceanographer to compute the intensity of subsurface daylight at various depths from measurements of its intensity above the surface. Attempts to this purpose will be made shortly from cruises with the "Skagerak".